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Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

DMS-DR 2455
NASA-CR 151,778

RESULTS OF FLOW ANGULARITY TESTS
ON A 0.0175-SCALE SPACE SHUTTLE ORBITER
MODEL (56-0) ON THE AEDC VKF "B"
HYPERSONIC WIND TUNNEL (0H102A)

SPACE SHUTTLE AEROTHERMODYNAMIC DATA REPORT

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Data Man AGEMENT SERVICES

MICHOUD DEFENSE SPACE DIVISION



CHRYSLER
CORPORATION

June, 1979

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HYPERSONIC WIND TUNNEL (0H102A)

by

W. F. Braddock
Rockwell International Space Systems Group
Field Operations, Huntsville

Prepared under NASA Contract Number NAS9-13247

by

Data Management Services
Chrysler Corporation Michoud Defense-Space Division
New Orleans, La. 70189

for

Engineering Analysis Division

Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas

WIND TUNNEL TEST SPECIFICS:

Test Number: AEDC HWTB V41B-65
NASA Series Number: OH102A
Model Number: 56-0
Test Dates: October 9, October 25, and November 29, 1978
Occupancy Hours: 12.5

FACILITY COORDINATOR:

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ABSTRACT

This report presents the results of flow angularity tests conducted on the vertical tail of a 0.0175-scale model of the Rockwell International Space Shuttle Orbiter. These tests were conducted in the Arnold Engineering and Development Center VKF "B" Hypersonic Wind Tunnel.

The tests were conducted at a nominal Mach number of 8, with tunnel Reynolds numbers varying between 0.5 and 3.7×10^6 per foot and model angles of attack varying between 30° and 40°.

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INTRODUCTION

The data presented in this report are the results of flow angularity tests conducted on a 0.0175-scale model of the Space Shuttle 140C Orbiter with a special "slab sided" vertical tail. The tests were conducted on the nights of October 9, October 29, and November 29, 1978. They were conducted in the Arnold Engineering and Development Center VKF "B" Hypersonic Wind Tunnel.

The purpose of the tests was to determine the flow direction at the SILTS location of the Orbiter vertical tail leading edge. The results will be used to establish design criteria for a total temperature and pressure rake to be used in OH400.

The model was tested at Mach 8 through a Reynolds number range of $0.5 \times 10^6/\text{ft.}$ to $3.7 \times 10^6/\text{ft.}$ The model angle-of-attack range tested was from 30° to 40° .

Included in this report are discussions of the configuration investigated, instrumentation, test facility, test procedure and data reduction. Also included are oil flow photographs and plotted data.

NOMENCLATURE

<u>Symbol</u>	<u>Definition</u>
L_0	Body Length, inches
P_0	Freestream Total Pressure, psia
RN/L	Freestream Unit Reynolds Number, per foot
T_0	Freestream Total Temperature, $^{\circ}$ R
X_0	Orbiter Body Station in X Direction, inches
Z_i	Spanwise Location as portion of Theoretical Span, percent
z_i	Spanwise Location Measured from Root, inches
Z_0	Orbiter Body Station in Z Direction, inches
α	Angle of Attack, degrees
β	Sideslip Angle, degrees
θ	Flow Angle, degrees

CONFIGURATION INVESTIGATED

The model used for these tests is model No. 2B of the material "LH" 56-0 phase change paint models (Figure 1, page 21). The pilot left fuselage side consists of a thinskin insert contoured to the vehicle lines (VL70-000140C). The model vertical tail (Figure 2, page 22) was constructed of stainless steel with the pilot left side being a flat slab coincident with the Orbiter plane of symmetry. The tip of the vertical tail extends past the theoretical tip to full scale $Z_0 = 858.57$ in order to study the complete area of the SILTS pod.

The following nomenclature was used to describe components of the vehicle 5 configuration:

B62	Fuselage
C12	Canopy
M16	OMS Pod
W127	Wing
E52	Elevon
F10	Body Flap
V30	Vertical

Table I contains full-and model-scale component dimensional data for the 56-0 model. Figure 3, page 23, presents the sting-mounted model, shown with a scaled vertical tail.

INSTRUMENTATION

Flow angularity was determined for most of the runs with the use of drops of oil placed on and near the leading edge of the vertical tail. The oil flowed across the surface of the tail upon injection into the tunnel flow. During runs 35 and 36, the oil was replaced with synthetic fiber tufts, taped to the vertical tail leading edge. Photographs were taken of the flow patterns at a rate of no less than one frame per second.

The 56-0 model is instrumented with eighty 30-gauge chromel constantan thermocouples (T/C's) but these were not used during this test.

TEST FACILITY DESCRIPTION

The Arnold Engineering Development Center (AEDC) is an Air Force Facility located in Tullahoma, Tennessee. The tunnel used, Tunnel B, is located in the Von Karman Facility portion of this center. Engineering and other technical operations in this tunnel are performed by contractor personnel of ARO, Inc.

Tunnel B is a continuous, closed-circuit, variable-density wind tunnel with an axisymmetric contoured nozzle and a 50-inch diameter test section. The tunnel can be operated at a nominal Mach number of 6 or 8 at stagnation pressures from 20 to 300 and 50 to 900 psia, respectively, and at a stagnation temperature of up to 1350°R. The model may be injected into the tunnel for a test run and then retracted for model cooling or model changes without interrupting the tunnel flow.

TEST PROCEDURE

The program was conducted at a nominal freestream Mach number of 8 and at five values of Reynolds number per foot. The nominal test conditions are presented in Table II and the complete run schedule in Table III.

The test program included angles of attack (α) of 30° , 32.5° , 35° , 37.5° , and 40° at zero yaw. The angles of attack were set using the pitch sector of the tunnel. To obtain the 30-to 40-degree α range, the model was mounted on a 15° prebent sting (Figure 4, Page 24) and support hardware that provided another 15° of incidence (Figure 5, Page 25). Due to the sector movement being restricted to the vertical plane, the 30° prebent α was the only angle of attack obtainable when the model was rolled 90° on its side. Figures 6, 7 and 8 (Pages 26, 27 and 28) show the model in the upright, 90° - rolled and inverted positions on the support structure. The photographs in Figures 6 and 7 were taken when the model was in the model preparation tank below the tunnel test section. The photograph in Figure 7 was taken through the windows of the test section.

Prior to each oil flow run, the vertical tail was cleaned and a pattern of dots or lines of oil was applied to the "slab" surface (left). The patterns varied from run to run in a continuing attempt to obtain the best defined oil flow possible. After the oil was applied, the model was inserted into the flow for a normal time of 5 to 7 seconds, and then retracted.

The tufts used in runs 35 and 36 were attached using metalic foil tape which was lapped over the leading edge of the vertical tail.

DATA REDUCTION

All flow angles were measured from the leading edge of the vertical tail with $\theta = 0$ indicating spanwise flow, as presented on Figure 3, page 23. Spanwise locations are specified as a percentage of the theoretical span.

$$Z_i = \frac{z_i}{\frac{z_0}{(\text{theo. tip})} - \frac{z_0}{(\text{Root})}} = \frac{z_i}{315.72}$$

Geometric relationships are presented on Figure 8, Page 29.

REFERENCES

1. Test Facilities Handbook (Tenth Edition). "Von Karman Gas Dynamics Facility, Vol. 3." Arnold Engineering Development Center, May 1974 SD75-SH-0118, V.
2. "Pretest Information for Testing the 56-0 0.0175 Scale Slab Tail Flow Angularity Model in the AEDC/VKF "B" Wind Tunnel" by W. F. Braddock, November 3, 1978.

TABLE I
MODEL DIMENSIONAL DATA

MODEL COMPONENT : BODY - B₆₂

GENERAL DESCRIPTION : Configuration 140C orbiter fuselage, MCR 200-R4

Similar to 140A/B fuselage except aft body revised and improved

midbody-wing-boot fairing, X₀ = 940 to X₀ = 1040.

MODEL SCALE: 0.0175

DRAWING NUMBER : VL70-000140C, -000202C, -000205A
VL70-000200B, -000203

DIMENSIONS :	FULL SCALE	MODEL SCALE
Length (IML: FWD Sta X ₀ =238), In.	<u>1290.3</u>	<u>22.58</u>
Length (OML: Fwd Sta X ₀ =235), In.	<u>1293.3</u>	<u>22.63</u>
Max Width (At X ₀ = 1528.3), In.	<u>264.0</u>	<u>4.62</u>
Max Depth (At X ₀ = 1464), In.	<u>250.0</u>	<u>4.38</u>
Fineness Ratio	<u>4.899</u>	<u>4.899</u>
Area - Ft ²	<u> </u>	<u> </u>
Max. Cross-Sectional	<u>340.885</u>	<u>0.104</u>
Planform	<u> </u>	<u> </u>
Wetted	<u> </u>	<u> </u>
Base	<u> </u>	<u> </u>

TABLE I (Continued)
MODEL DIMENSIONAL DATA

MODEL COMPONENT : CANOPY - C₁₂

GENERAL DESCRIPTION : Configuration 140C orbiter canopy. Vehicle cabin No. 31 updated to MCR 200-R4. Used with fuselage B₆₂.

MODEL SCALE: 0.0175

DRAWING NUMBER : VL70-000140C, -000202B, -000204

DIMENSIONS :	FULL SCALE	MODEL SCALE
Length (X_0 = 434.643 to 578), In.	<u>143.357</u>	<u>2.508</u>
Max Width (At X_0 = 513.127), In.	<u>152.412</u>	<u>2.667</u>
Max Depth (Z_0 = 501 to 449.39), In.	<u>51.61</u>	<u>0.903</u>
Fineness Ratio	_____	_____
Area	_____	_____
Max. Cross-Sectional	_____	_____
Planform	_____	_____
Wetted	_____	_____
Base	_____	_____

TABLE I (Continued)
MODEL DIMENSIONAL DATA

MODEL COMPONENT: ELEVON - E₅₂

GENERAL DESCRIPTION: Elevon for configuration 140C. Hingeline at X_o = 1387,
elevon split line X_w = 312.5, 6.0", beveled edges, and centerbodies.

MODEL SCALE: 0.0175

DRAWING NUMBER: VL70-000140C, -006089, -006092

DIMENSIONS:

	<u>FULL-SCALE</u>	<u>MODEL SCALE</u>
Area - Ft ²	<u>210.0</u>	<u>0.064</u>
Span (equivalent) - In.	<u>349.2</u>	<u>6.111</u>
Inb'd equivalent chord- In.	<u>118.0</u>	<u>2.065</u>
Outb'd equivalent chord	<u>55.19</u>	<u>0.966</u>
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord	<u>0.2096</u>	<u>0.2096</u>
At Outb'd equiv. chord	<u>0.4004</u>	<u>0.4004</u>
Sweep Back Angles, degrees		
Leading Edge	<u>0.0</u>	<u>0.0</u>
Tailing Edge	<u>-10.056</u>	<u>-10.056</u>
Hingeline (Product of area & c)	<u>0.0</u>	<u>0.0"</u>
Area Moment (Product of area & Z _o) Ft ³	<u>1587.25</u>	<u>0.008</u>
Mean Aerodynamic Chodr, In.	<u>90.7</u>	<u>1.587</u>
Hingeline dihedral (origin at Z _o = 261.3509), deg.	<u>5.229</u>	<u>5.229</u>

TABLE I (Continued)

MODEL DIMENSIONAL DATA

MODEL COMPONENT : BODY FLAP - F₁₀GENERAL DESCRIPTION : Configuration 140C body flap. Hingeline located at X_o = 1532, Z_o = 287.MODEL SCALE: 0.0175DRAWING NUMBER: VL70-000140C, -355114

DIMENSIONS :

FULL SCALE

MODEL SCALE

Length (X_o = 1525.5 to X_o = 1613), In. 87.50 1.531Max Width (At L.E., X_o = 1525.5), In. 256.00 4.480Max Depth (X_o = 1532), In. 19.798 0.346Fineness Ratio Area - Ft² Max. Cross-Sectional (At H. L.) 35.196 0.011Planform 135.00 0.041Wetted Base (X_o = 1613) 4.89 0.0015

TABLE I (Continued)
MODEL DIMENSIONAL DATA

MODEL COMPONENT : OMS POD - M₁₆

GENERAL DESCRIPTION : Configuration 140C orbiter OMS Pod - short pod.

MODEL SCALE: 0.0175

DRAWING NUMBER : VL70-008401, -008410

DIMENSIONS :

	FULL SCALE	MODEL SCALE
Length (OMS Fwd Sta X_0 = 1310.5), In.	<u>258.50</u>	<u>4.524</u>
Max Width (At X_0 = 1511), In.	<u>136.8</u>	<u>2.394</u>
Max Depth (At X_0 = 1511), In.	<u>74.70</u>	<u>1.307</u>
Fineness Ratio	<u>2.484</u>	<u>2.484</u>
Area = Ft ²		
Max. Cross-Sectional	<u>58.864</u>	<u>0.018</u>
Planform		
Wetted		
Base		

TABLE 1 (Continued)

MODEL DIMENSIONAL DATA

MODEL COMPONENT: VERTICAL - V30

GENERAL DESCRIPTION: Slab sided vertical tail with extended span

MODEL SCALE: 0.0175

DIMENSIONS:

	<u>FULL SCALE</u>	<u>MODEL SCALE</u>
TOTAL DATA		
Area (Theo) - Ft ²	<u>442.299</u>	<u>0.135</u>
Planform		
Span - In.	<u>358.57</u>	<u>6.275</u>
Aspect Ratio	<u>2.019</u>	<u>2.019</u>
Rate of Taper	<u>0.507</u>	<u>0.507</u>
Taper Ratio	<u>0.323</u>	<u>0.323</u>
Sweep-Back Angles, Degrees		
Leading Edge	<u>45.000</u>	<u>45.000</u>
Trailing Edge	<u>26.25</u>	<u>26.25</u>
0.25 Element Line	<u>41.13</u>	<u>41.13</u>
Chords:		
Root (Theo) WP	<u>268.50</u>	<u>4.699</u>
Tip (Theo) WP	<u>86.75</u>	<u>1.518</u>
MAC	<u>193.12</u>	<u>3.380</u>
Fus. Sta. of .25 MAC	<u>1474.87</u>	<u>25.801</u>
W.P. of .25 MAC	<u>648.71</u>	<u>11.352</u>
B.L. of .25 MAC	<u>0.0</u>	<u>0.0</u>
Airfoil Section		
Leading Wedge Angle - Deg.	<u>11.75</u>	<u>11.75</u>
Trailing Wedge Angle - Deg	<u>0.0</u>	<u>0.0</u>
Leading Edge Radius	<u>0.0</u>	<u>0.0</u>
Void Area	<u>0.0</u>	<u>0.0</u>
Blanketed Area	<u>0.0</u>	<u>0.0</u>

TABLE I (Concluded)
MODEL DIMENSIONAL DATA

MODEL COMPONENT: WING-W₁₂₇

GENERAL DESCRIPTION: Configuration 140C orbiter wing, MCR 200-R4. Similar to 140A/B wing W₁₁₆ but with refinements: improved wing-boot-midbody fairing ($X_0 = 940$ to $X_0 = 1040$). Elevon split line relocated from $Y_0 = 281$ to $Y_0 = 312.5$.

MODEL SCALE: 0.0175

TEST NO.

DWG. NO. VL70-000140C, -000200B

DIMENSIONS:

TOTAL DATA

Area (Theo.) Ft²

Planform

Span (Theo) In.

Aspect Ratio

Rate of Taper

Taper Ratio

Dihedral Angle, degrees

Incidence Angle, degrees

Aerodynamic Twist, degrees

Sweep Back Angles, degrees

Leading Edge

Trailing Edge

0.25 Element Line

Chords:

Root (Theo) B.P.O.O.

Tip, (Theo) B.P.

MAC

Fus. Sta. of .25 MAC

W.P. of .25 MAC

B.L. of .25 MAC

FULL-SCALE

MODEL SCALE

2690.00

0.824

936.68

16.392

2.265

2.265

1.177

1.177

0.200

0.200

3.500

3.500

0.500

0.500

3.000

3.000

45.000

45.000

- 10.065

- 10.065

35.209

35.209

689.24

12.062

137.85

2.412

474.81

8.309

1136.83

19.895

290.58

5.085

182.18

3.187

EXPOSED DATA

Area (Theo) Ft²

Span, (Theo) In. BP108

Aspect Ratio

Taper Ratio

Chords

Root BP108

Tip $\frac{1.00}{2}$

MAC

Fus. Sta. of .25 MAC

W.P. of .25 MAC

B.L. of .25 MAC

Airfoil Section (Rockwell Mod NASA)

XXXX-64

1751.50

0.536

720.68

12.612

2.059

2.059

0.245

0.245

562.09

9.837

137.85

2.412

392.83

6.875

1185.98

20.755

294.30

5.500

251.77

4.406

0.113

0.113

Root $b = \frac{2}{2}$

0.120

0.120

Tip $b = \frac{2}{2}$

Data for (1) or (2) Sides

Leading Edge Cuff Ft²

Planform Area Ft²

Leading Edge Intersects Fus M. L. @ Sta

Leading Edge Intersects Wing @ Sta

113.18

0.035

500.00

8.750

1024.0

17.920

TABLE II

TABLE III.

TEST: OH-102A		DATA SET/RUN NUMBER COLLATION SUMMARY						DATE: 11/30/78	
DATA SET IDENTIFIER	CONFIGURATION	$R_e/\ell \times 10^{-6}$							TEST RUN NUMBERS
		0C	β	0.5	1.0	2.0	3.2	3.7	
	ORBITER W/SLAB TAIL								
	UPRIGHT	30°	0°	3	6	1	2		
		32.5°				9			
		35°		5	8				
		40°		$4/14$	7				
	LEFT SIDE UP	30°	0°	24	$34/35^*$	25			
	INVERTED	30°	0°	11	18		26		
		32.5°		16	$21/22$		29		
		35°		13	19		$27/32$		
		37.5°		15	23	33	30		
		40°		12	20	36^*	28		
1									
7									
13									
19									
25									
31									
37									
43									
49									
55									
61									
67									
75									
76									
		COEFFICIENTS							IDVAR (1) IDVAR (2) NDV
α OR β SCHEDULES									

* TUFTS

21

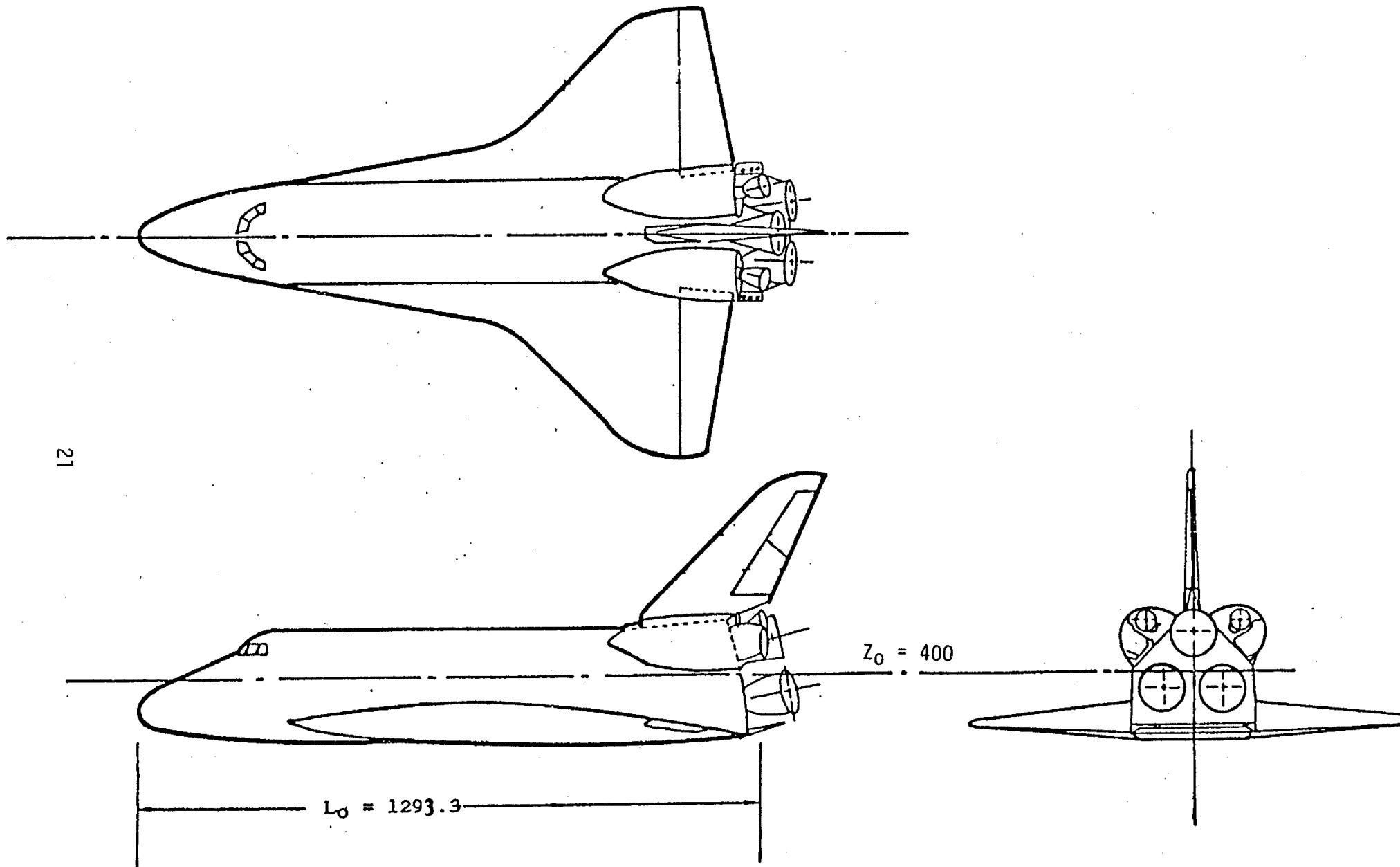


Figure 1. Model General Layout with Scaled Vertical Tail

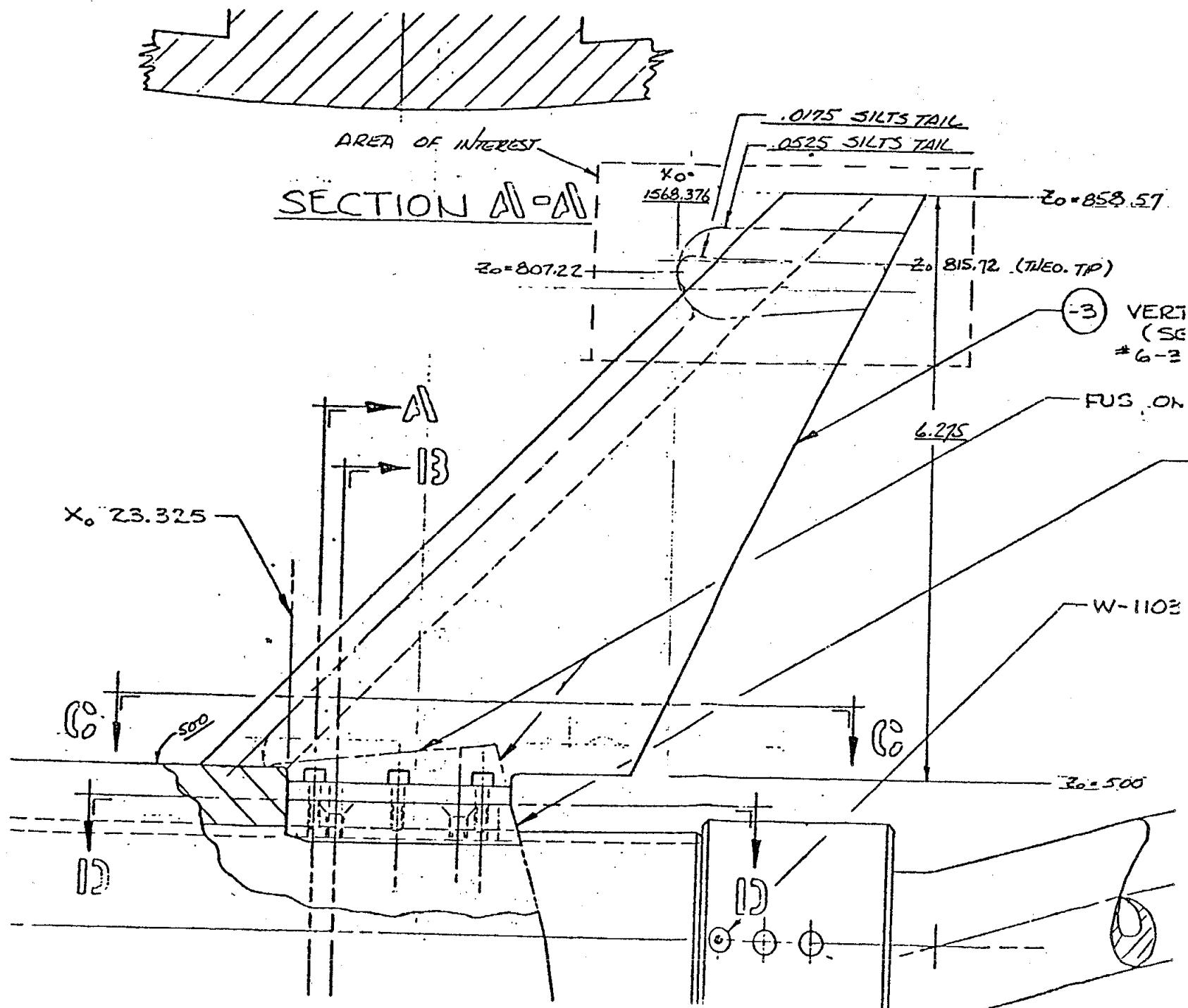


Figure 2. Vertical Tail

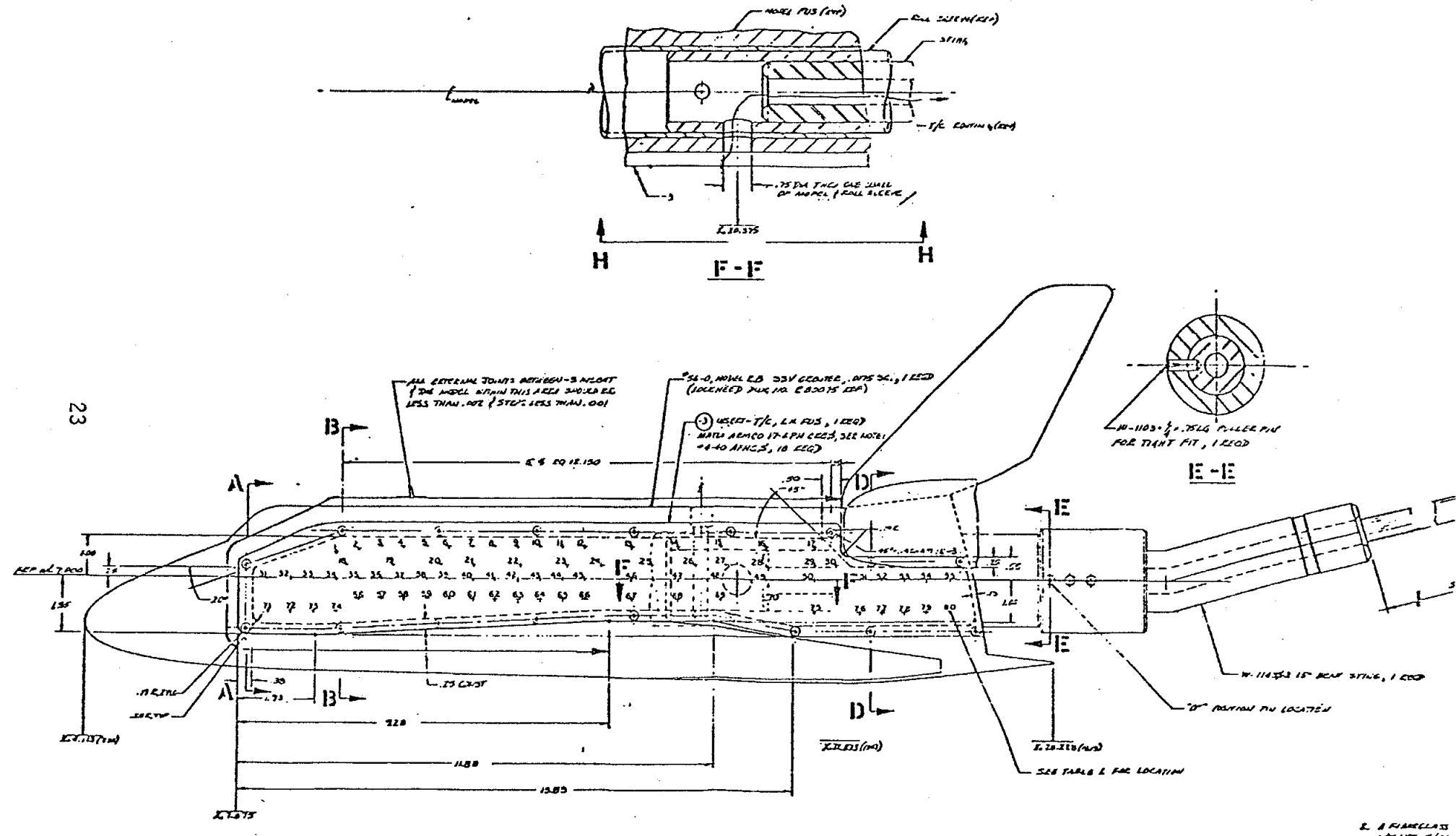
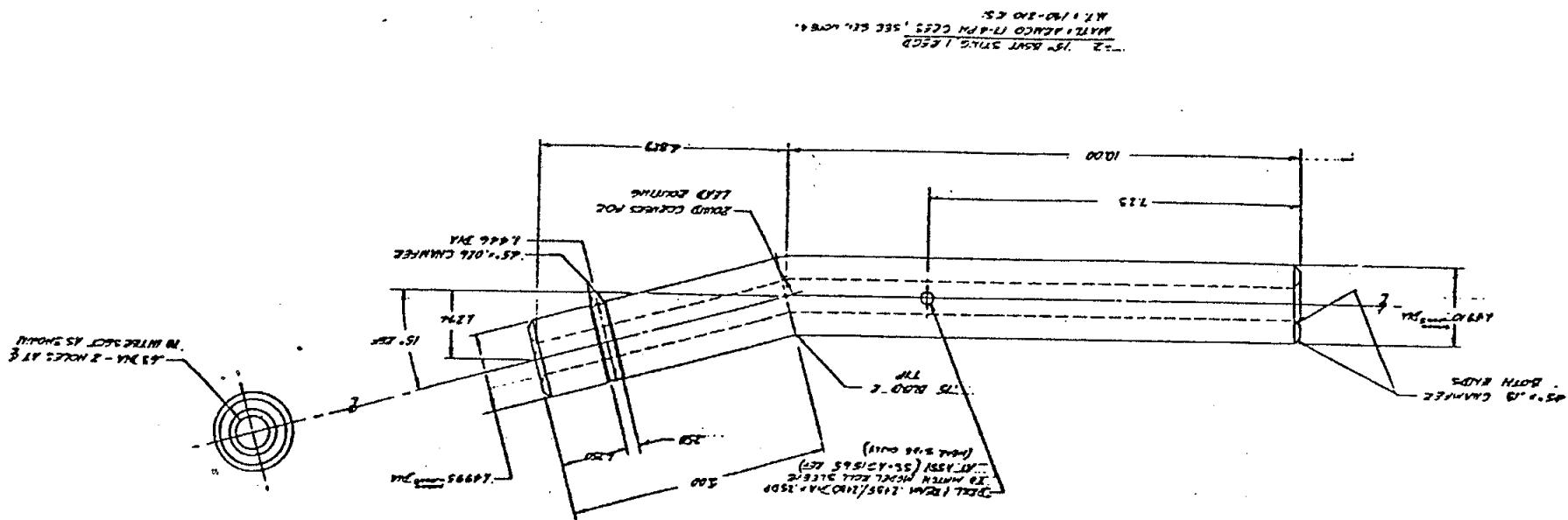


Figure 3. Sting-Mounted Model

Figure 4. 150 Prebent Sting



50-INCH HYPERSONIC TUNNELS B&C

SCALE - 1/3

TUNNEL WALL

MAX. FWD. PT
STA. 69 673

FWD. C.R.
STA. 59 673

NOM. C.R.
STA. 43 673

AFT. C.R.
STA. 29 673

ROLL HUB
STA. 0 00

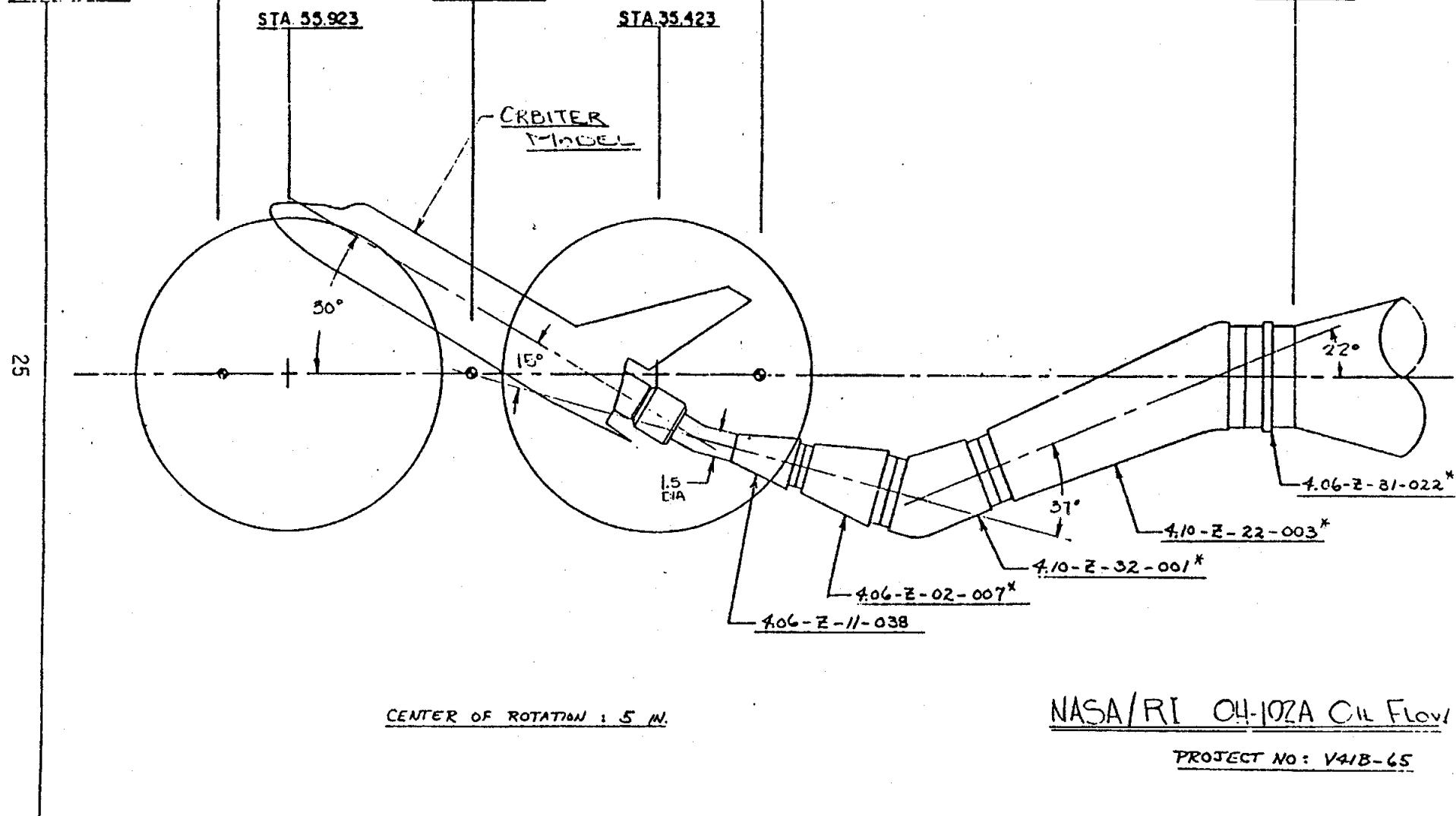


Figure 5. Model Installation

NASA/RI OH-102A Oil Flow

PROJECT NO: V41B-65

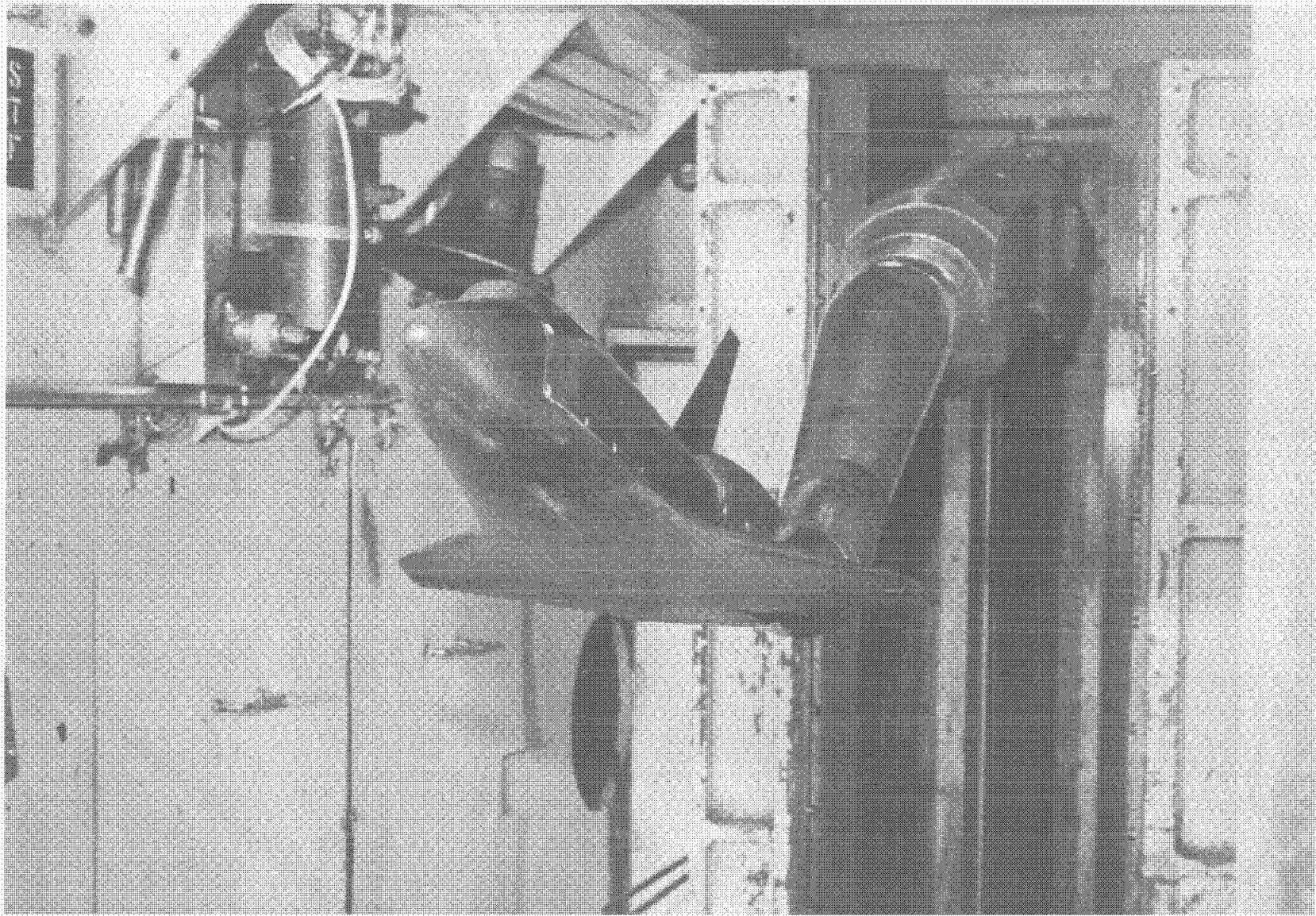


Figure 6. Model in Upright Position

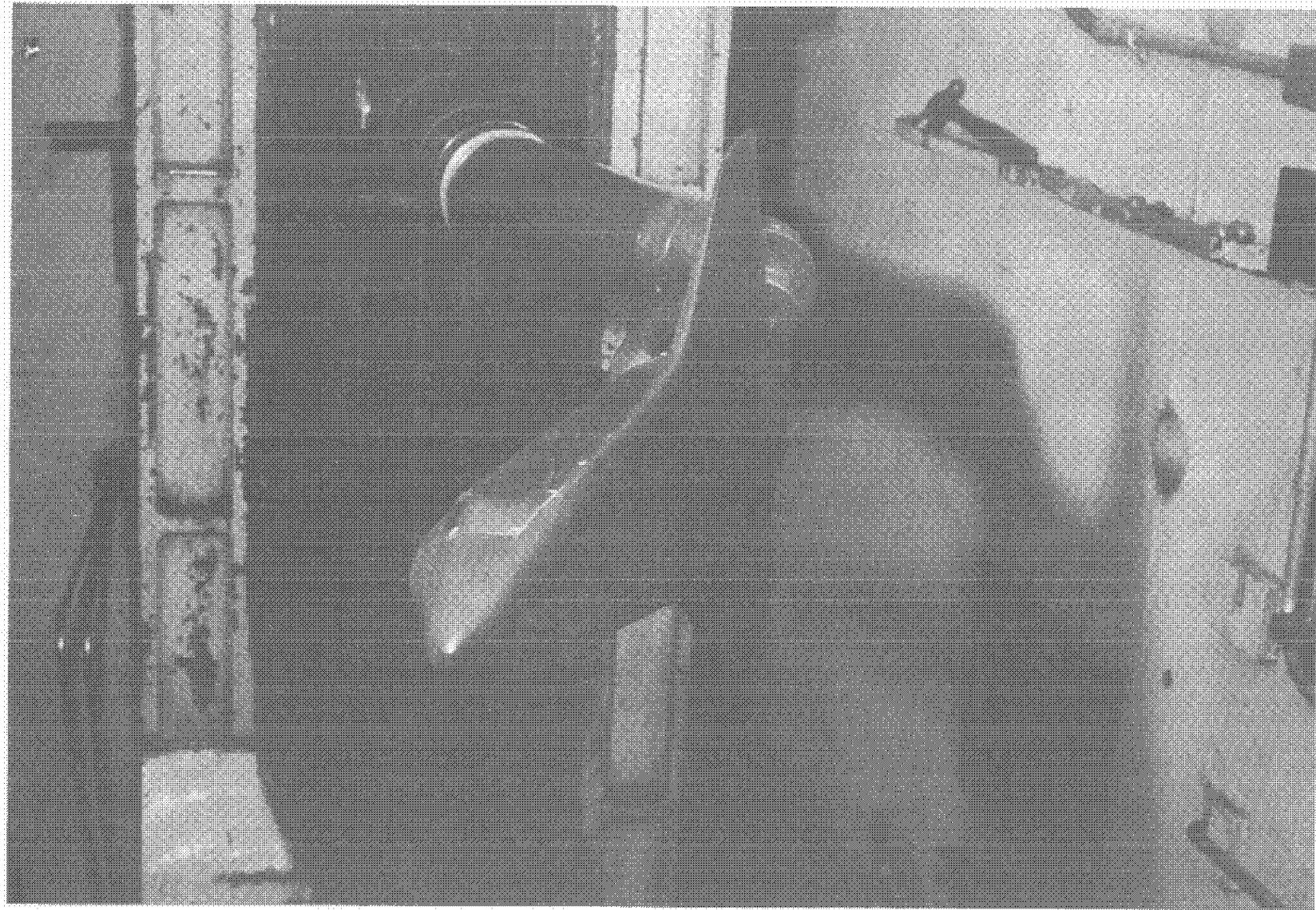


Figure 7. Model Rolled 90° to Right

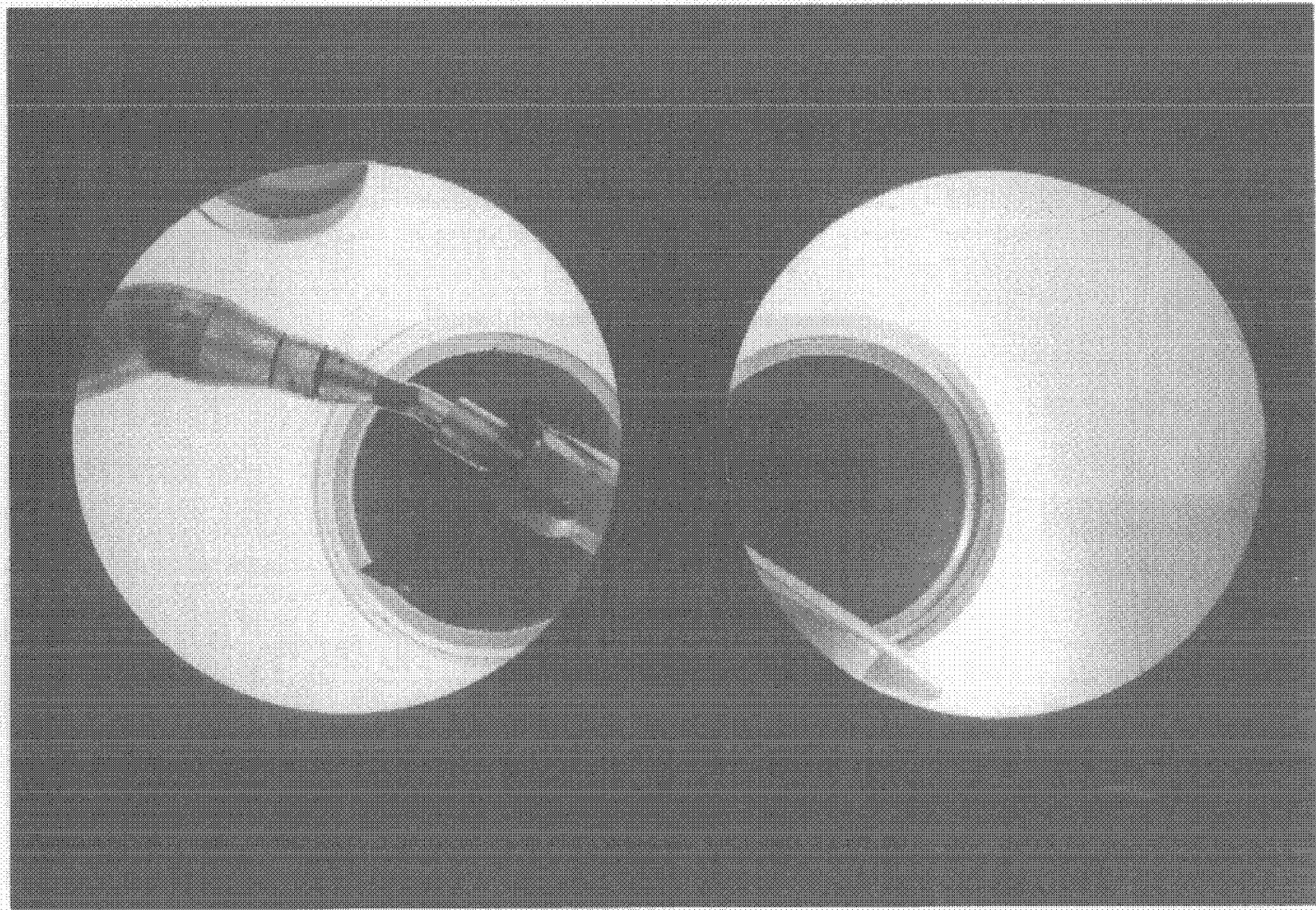


Figure 8. Model in Inverted Position

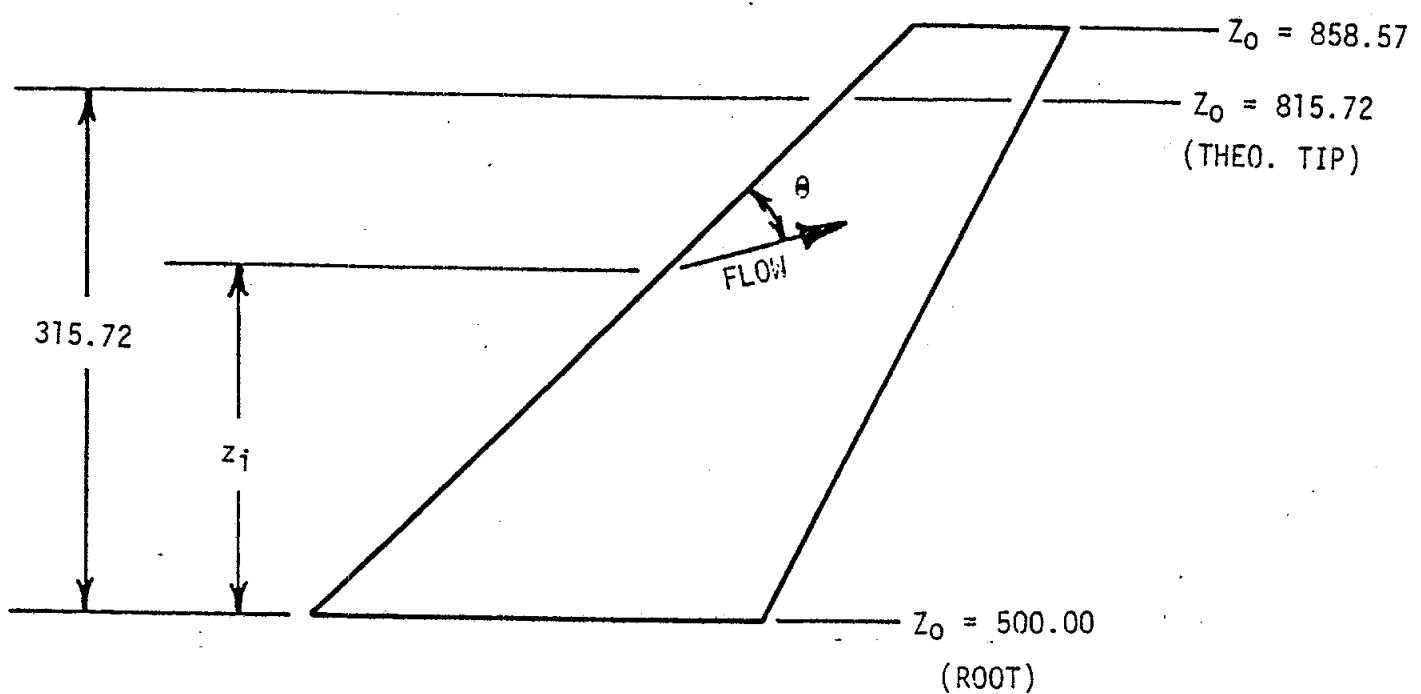


Figure 9. Flow Angle Measurements

Notes:

1. Positive directions of angles are indicated by arrows
2. For clarity, origins of wind and stability axes have been displaced from the center of gravity

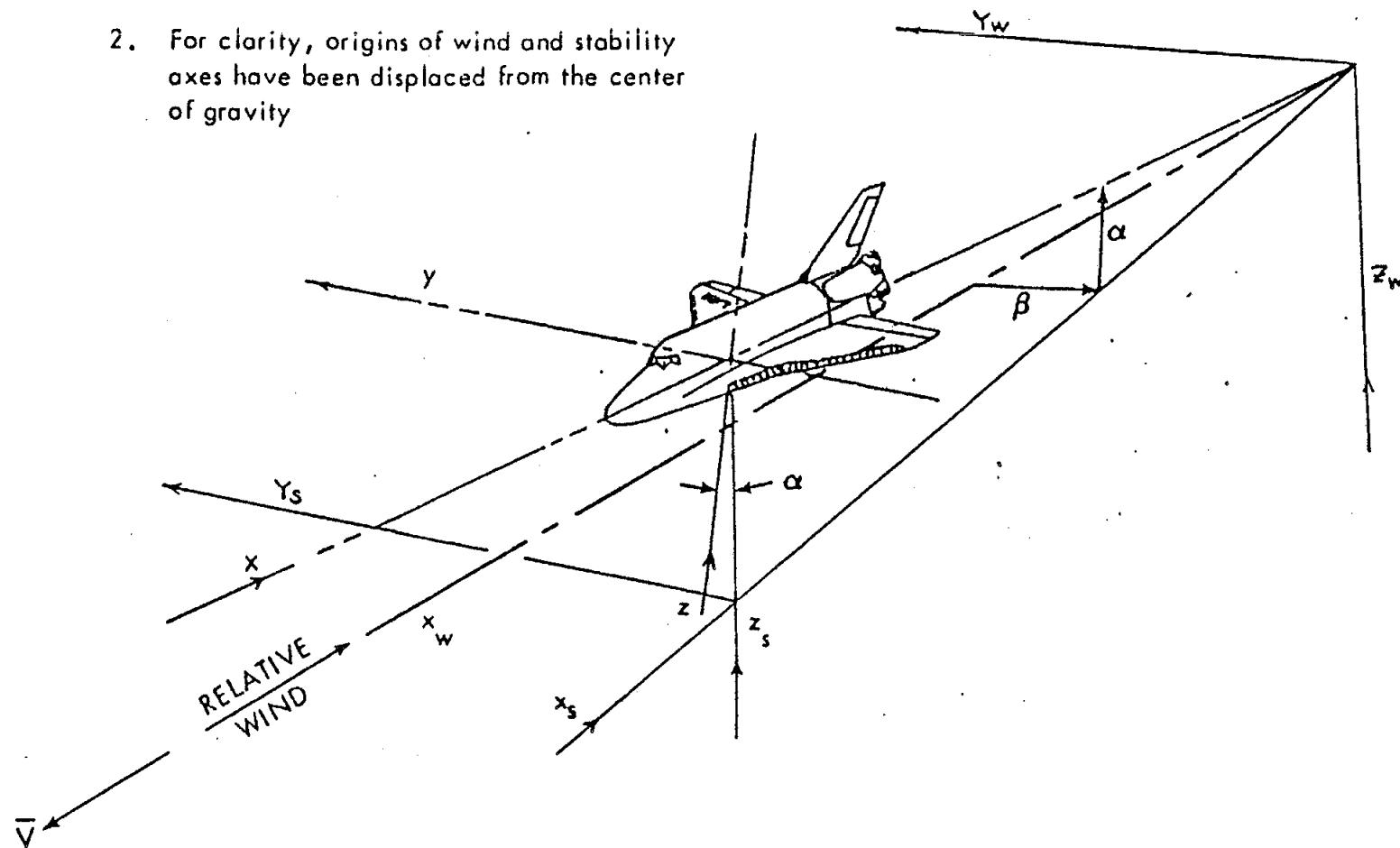


Figure 10. - Axis Systems

DATA FIGURES

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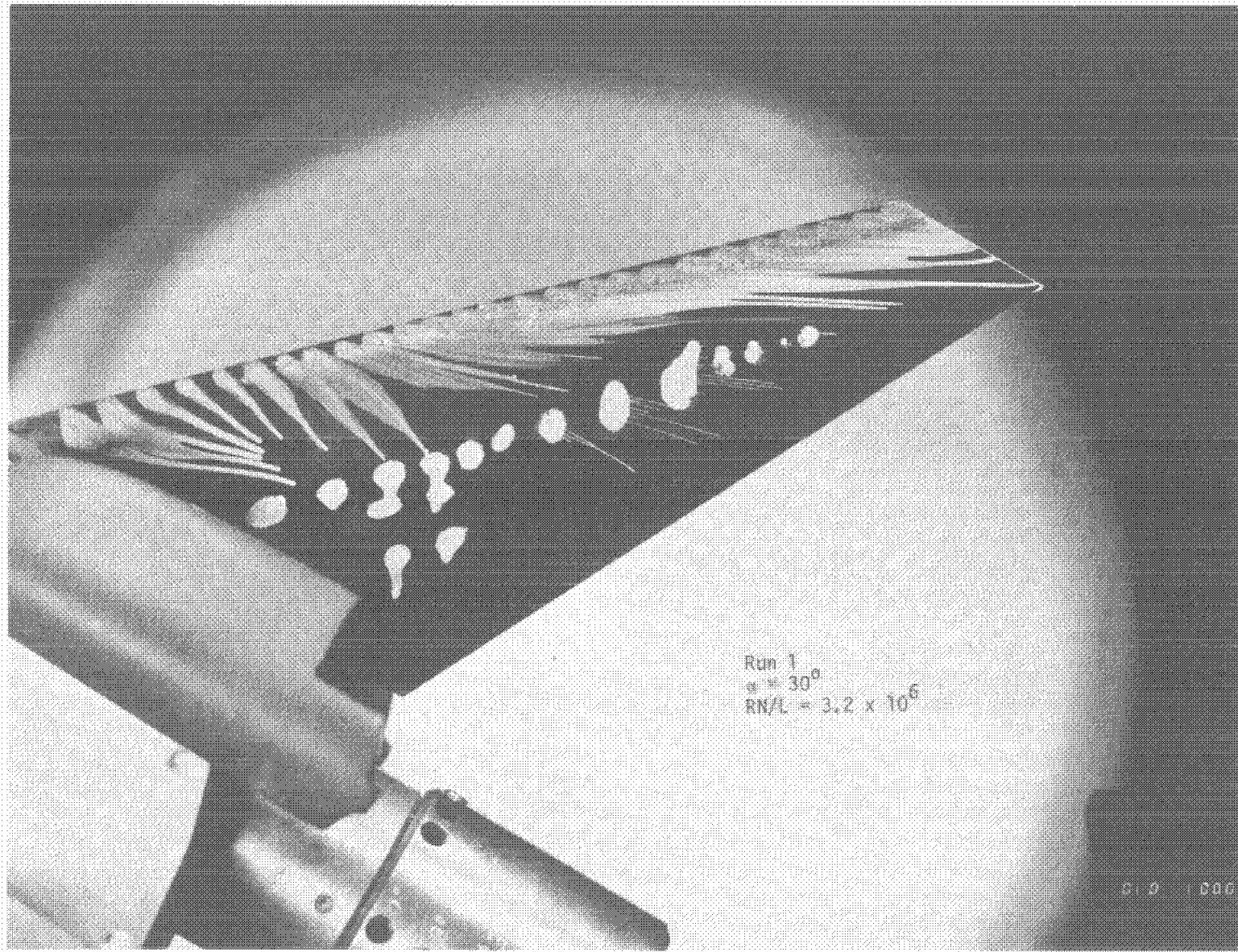


Figure 11. Oil Flow

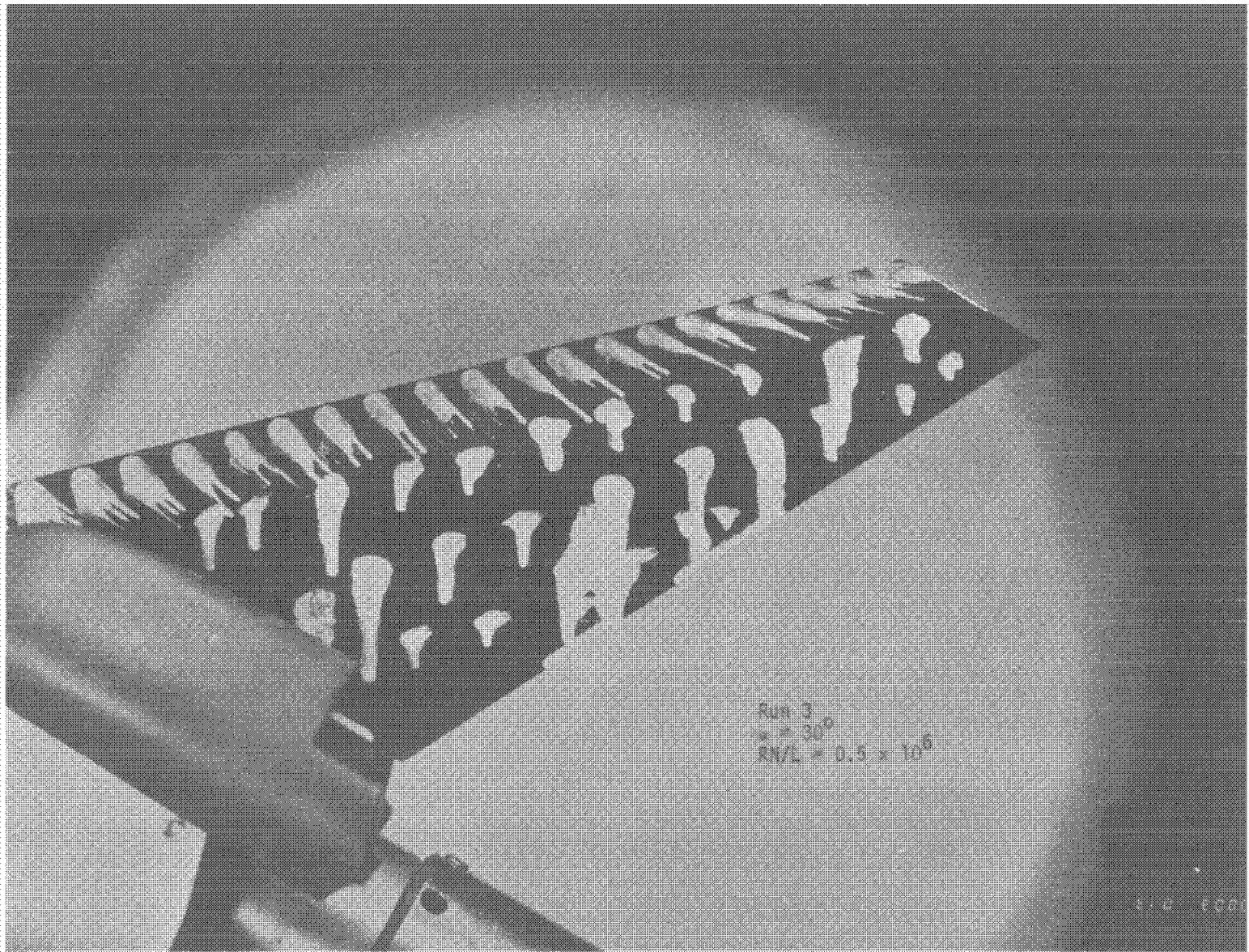


Figure 12. Oil Flow

34

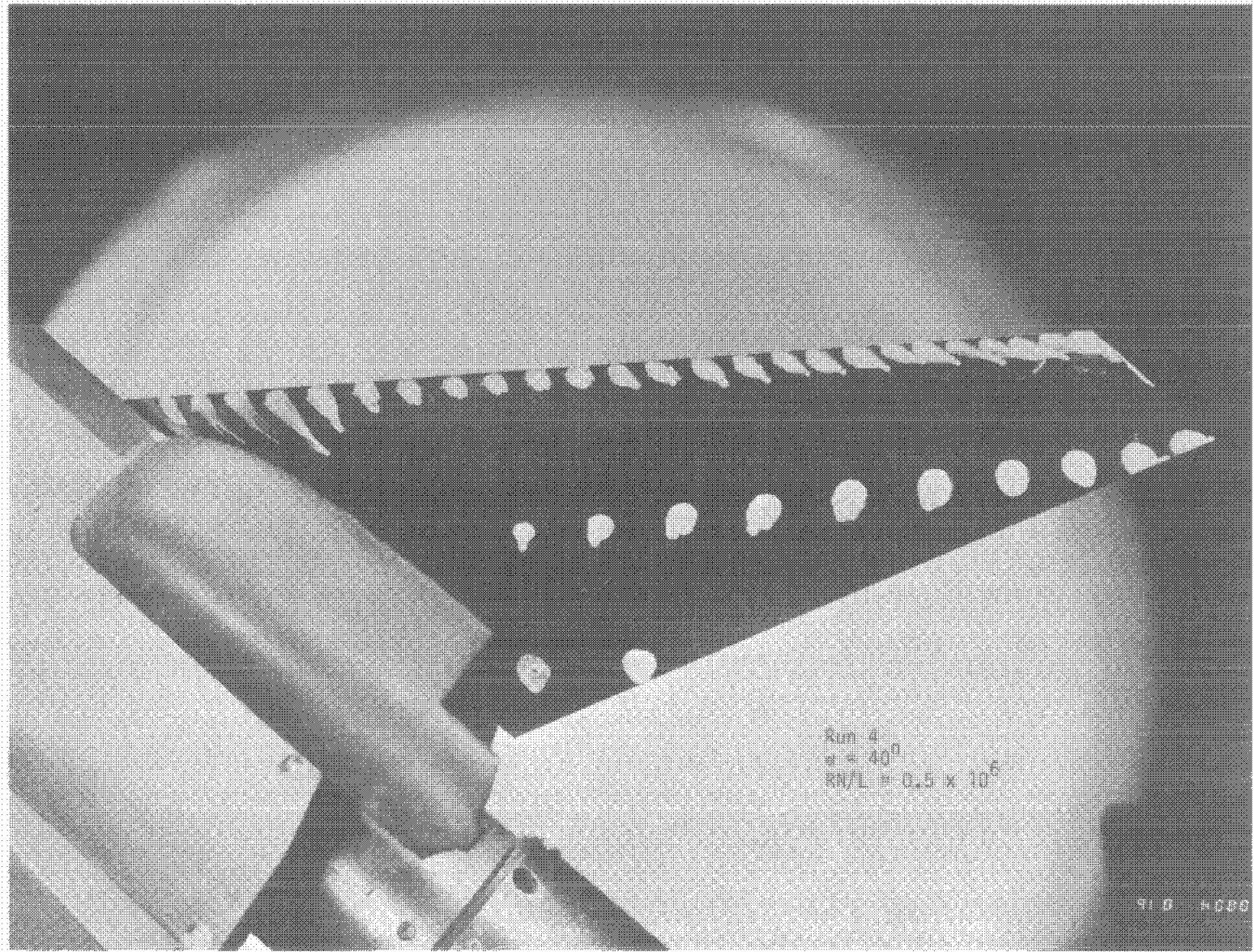


Figure 13. Oil Flow

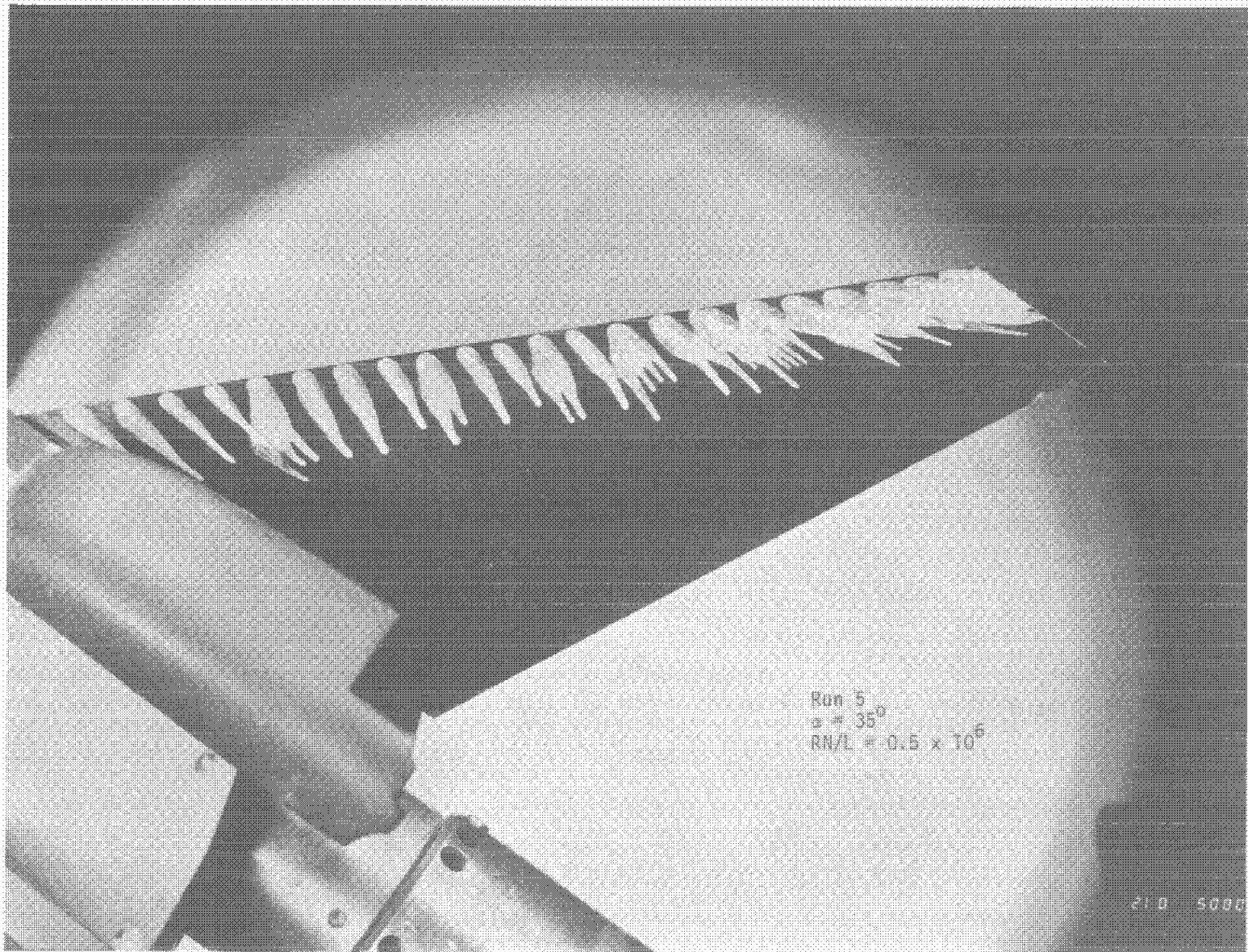


Figure 14. Oil Flow

36

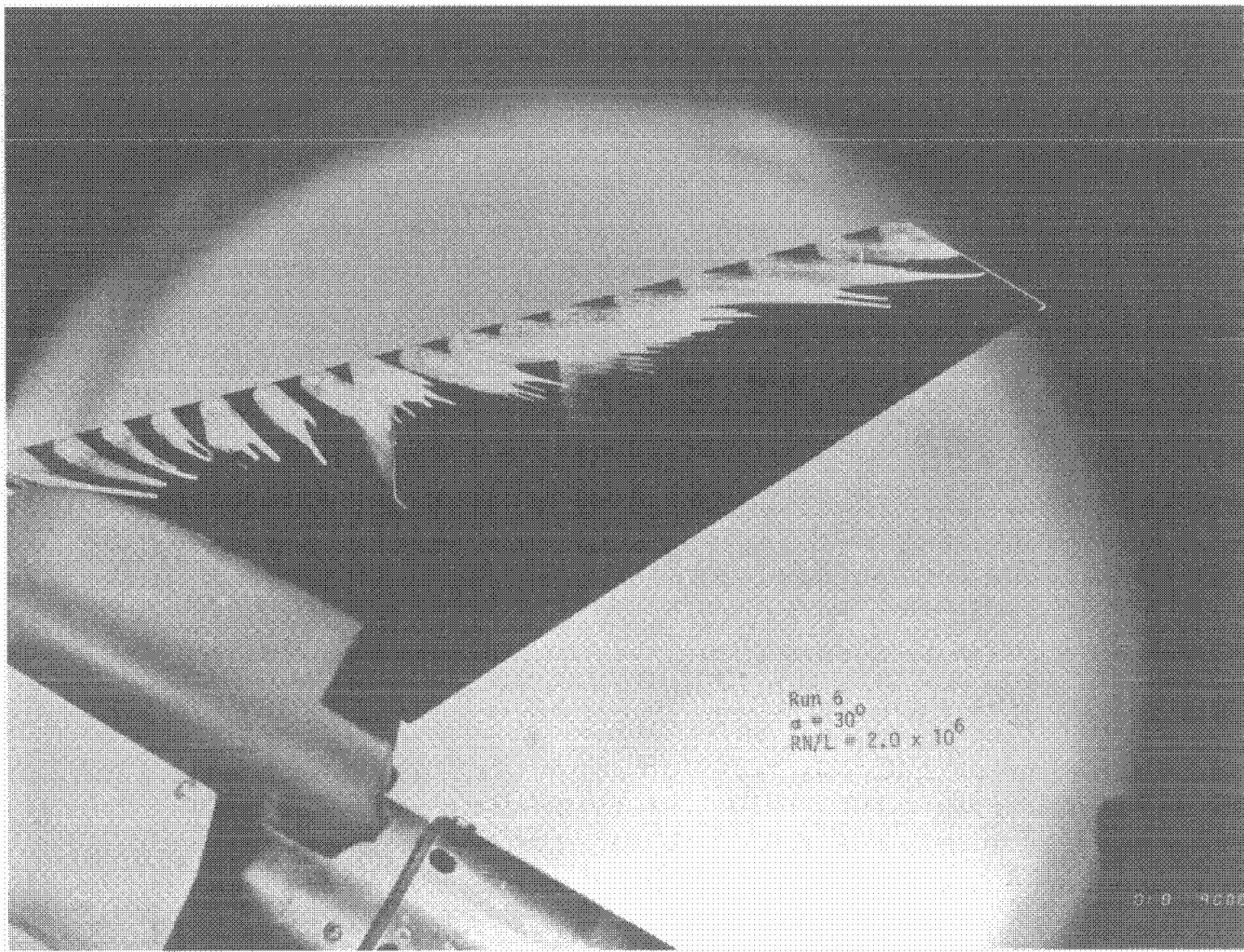


Figure 15. 011 Flow

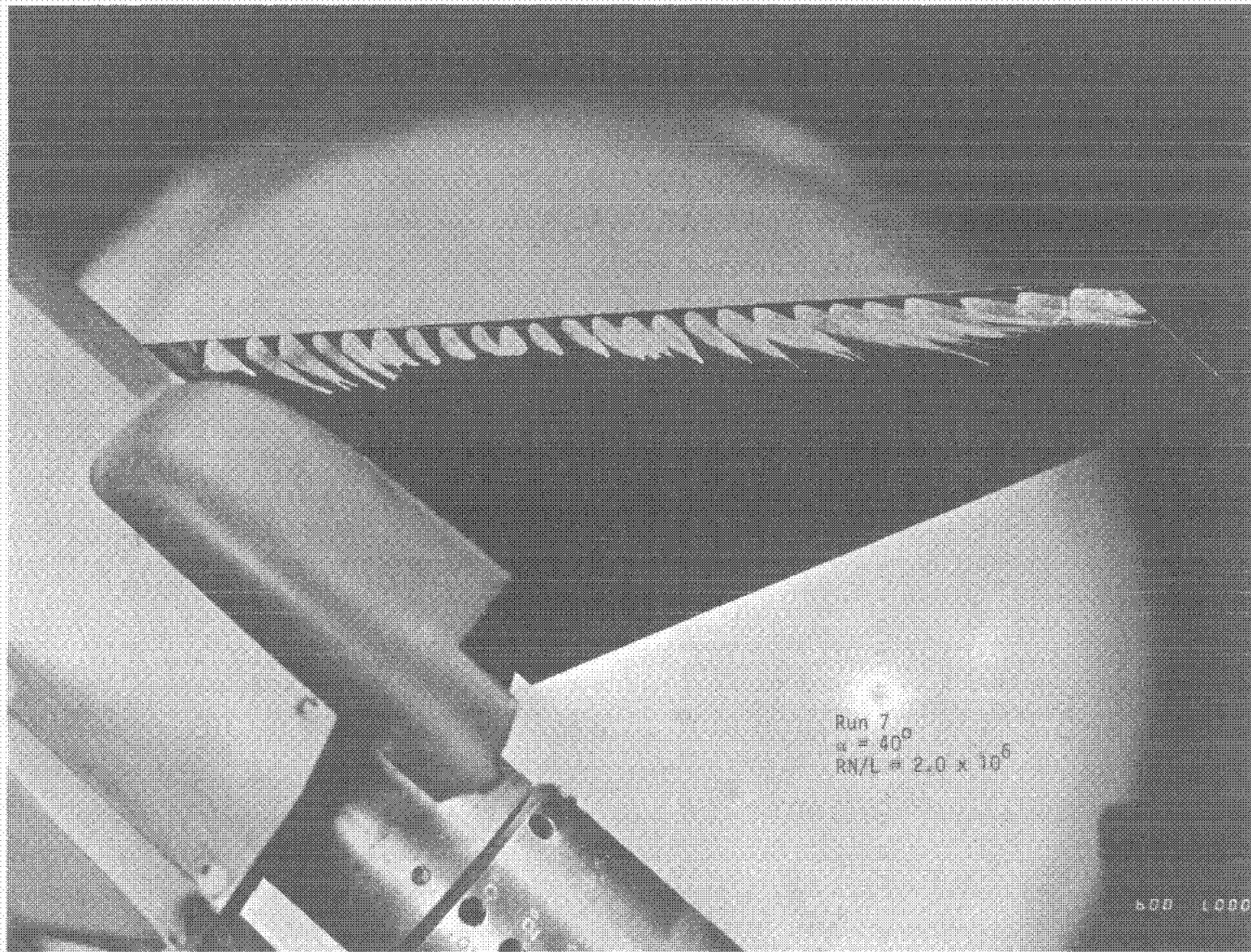


Figure 16. Oil Flow

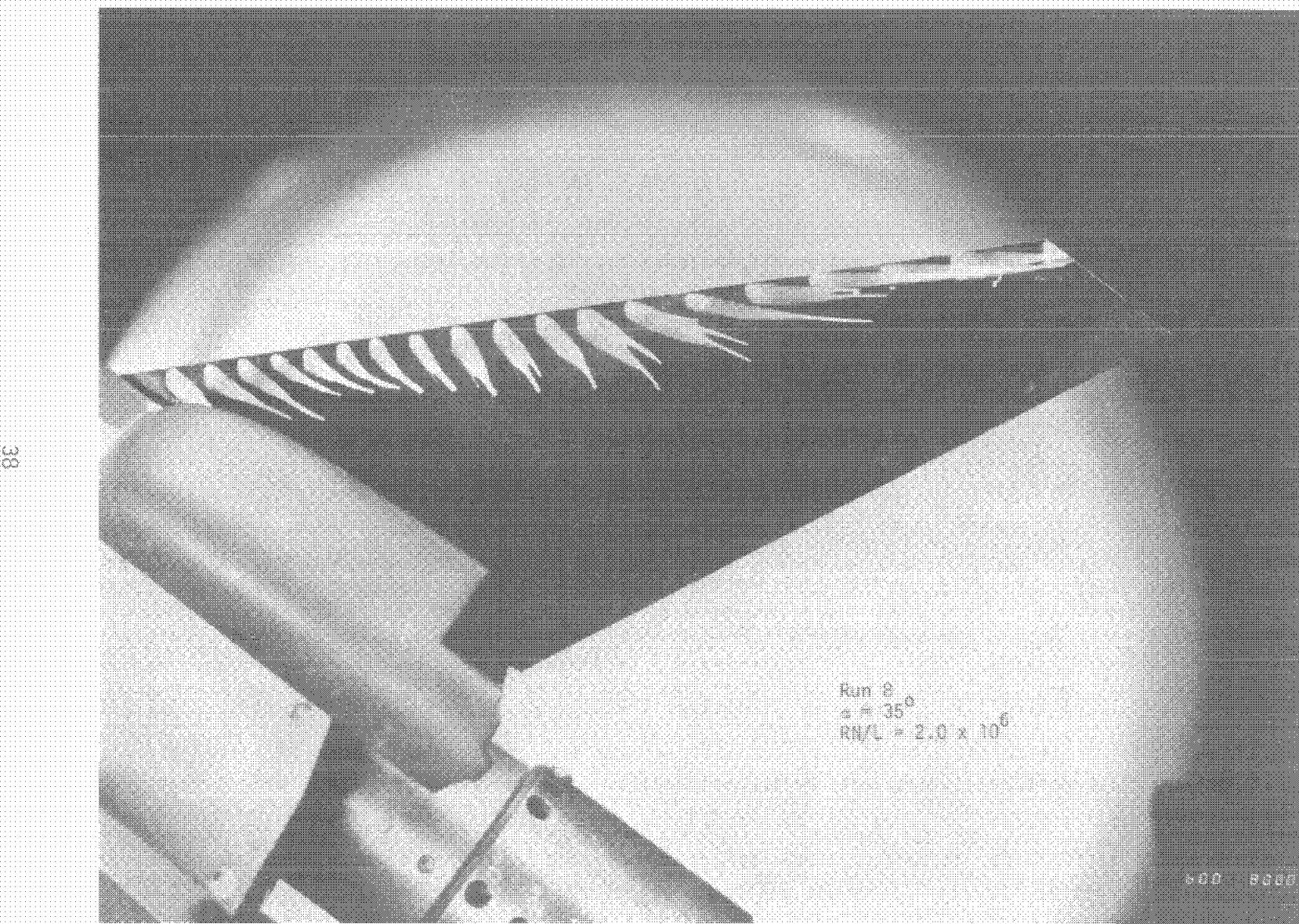


Figure 17. Oil Flow

39

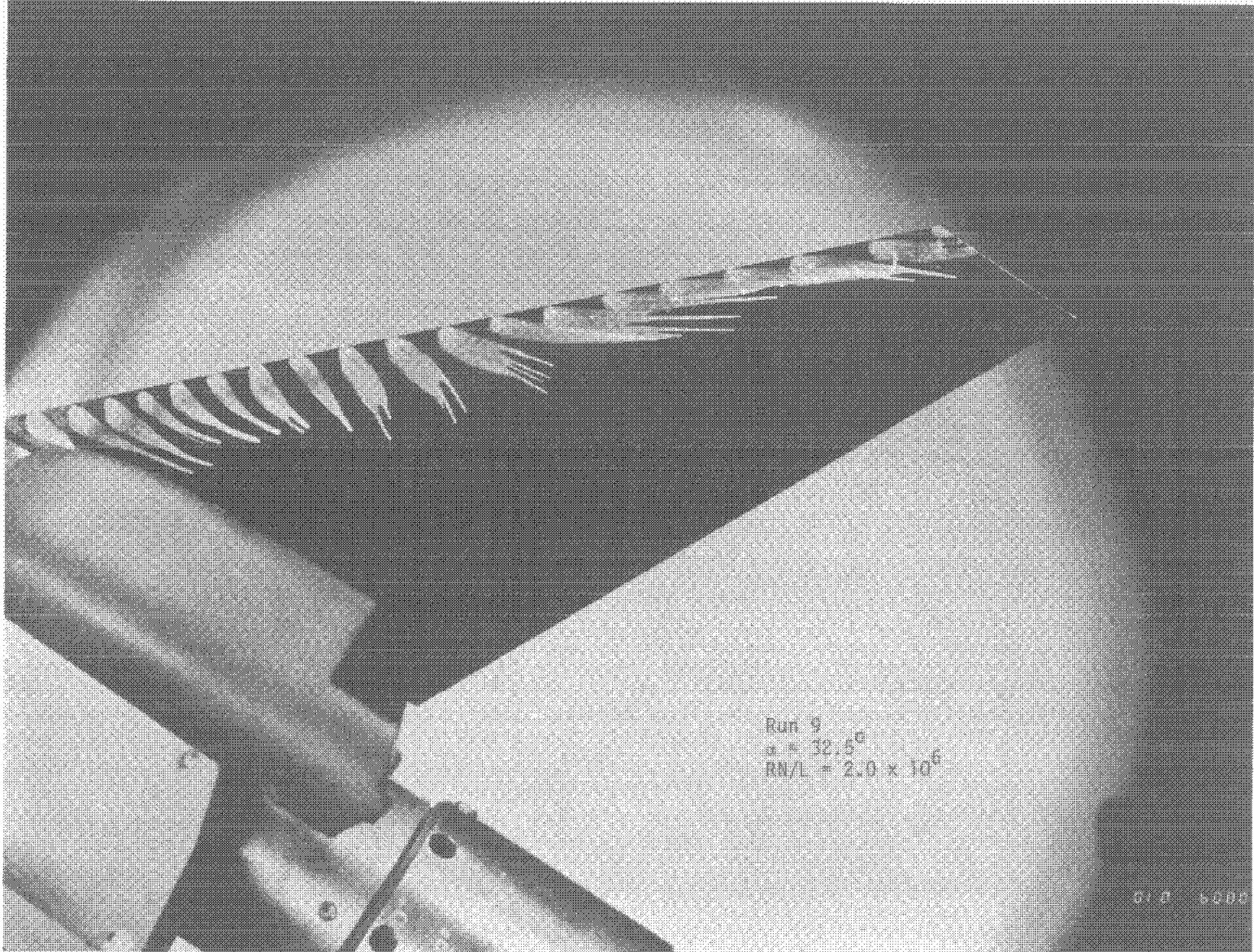


Figure 18. Oil Flow

40

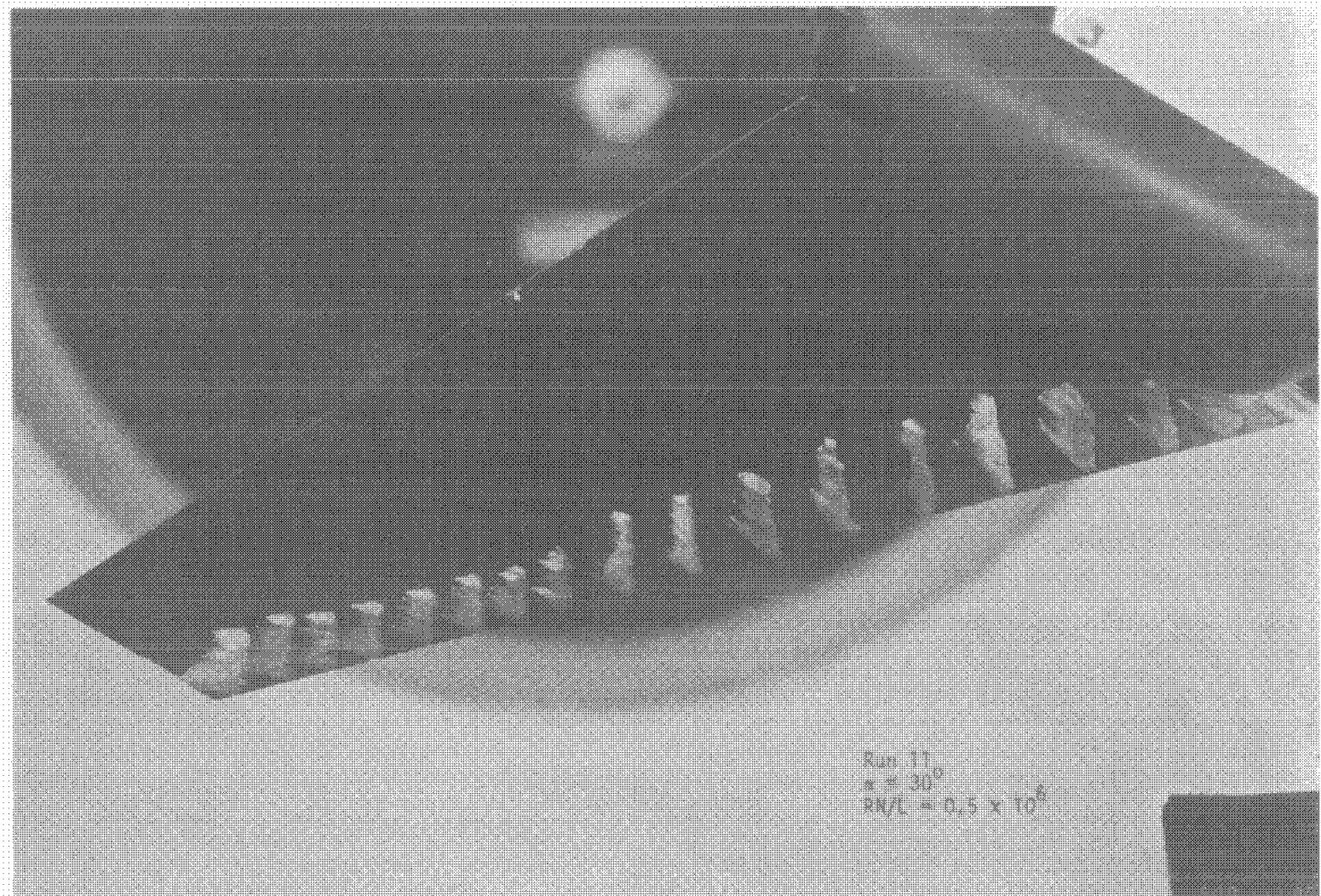


Figure 19. Oil Flow

41

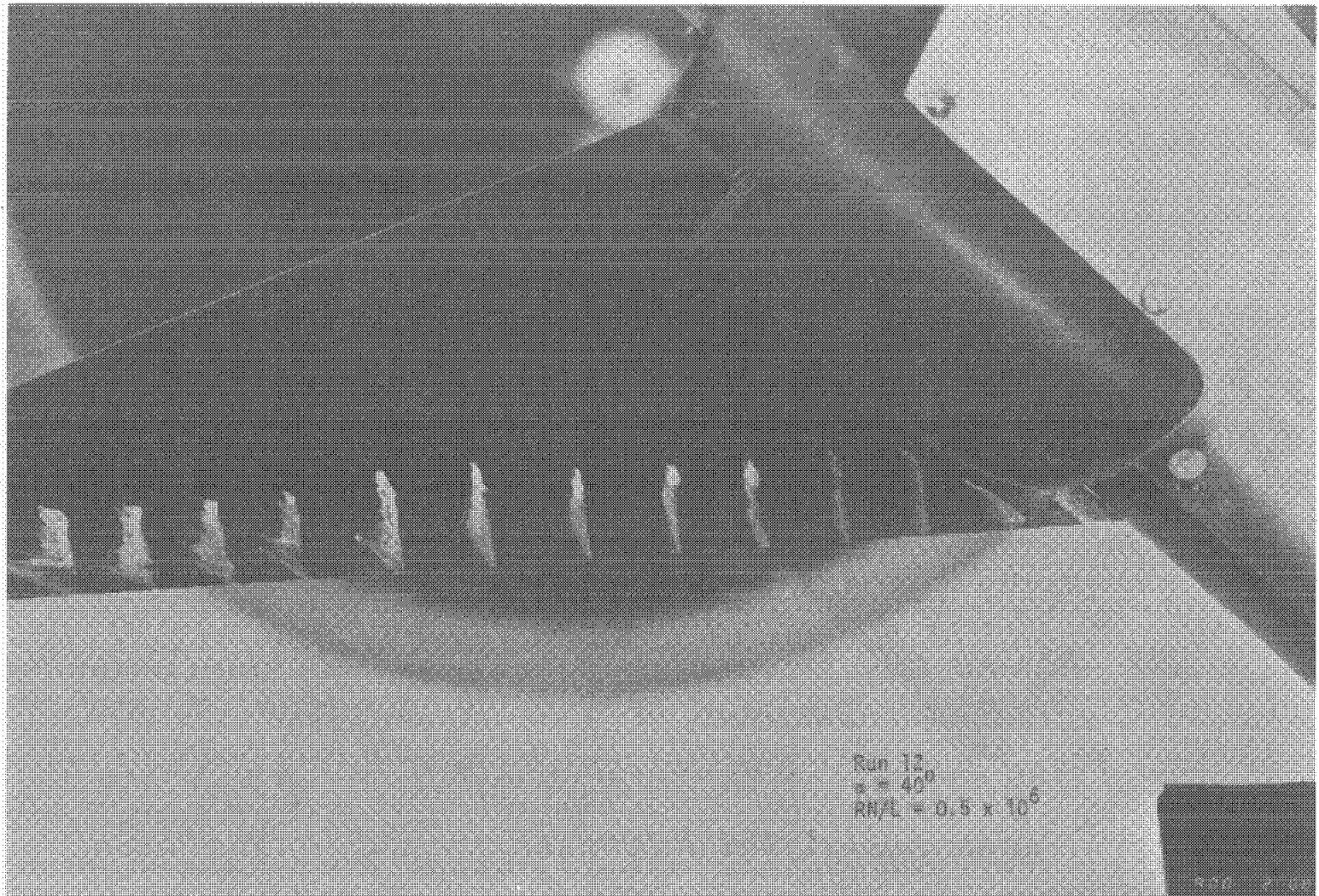


Figure 20. Oil Flow

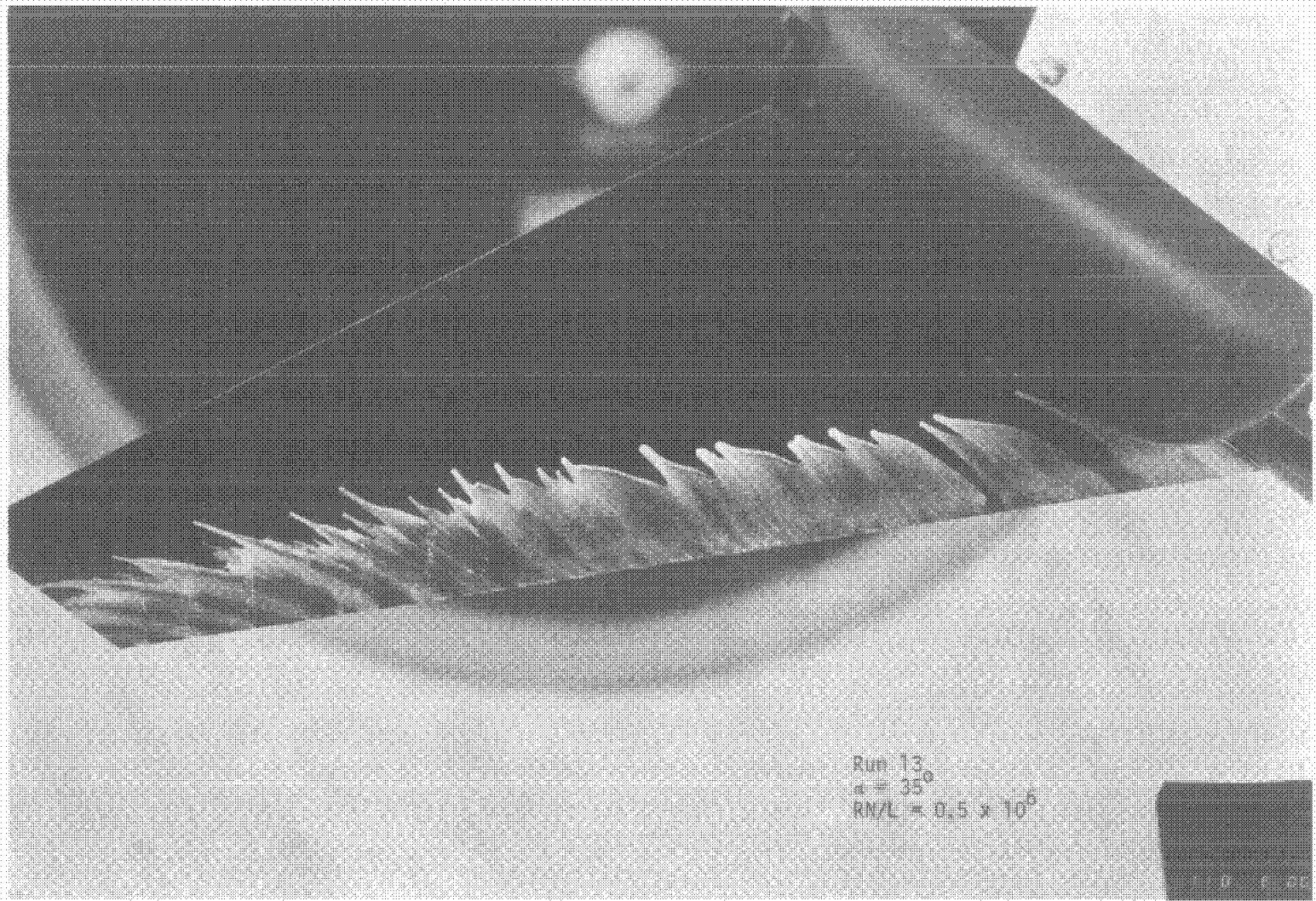


Figure 21. Oil Flow

Run 13
 $\alpha = 35^\circ$
 $RM/L = 0.5 \times 10^6$

43

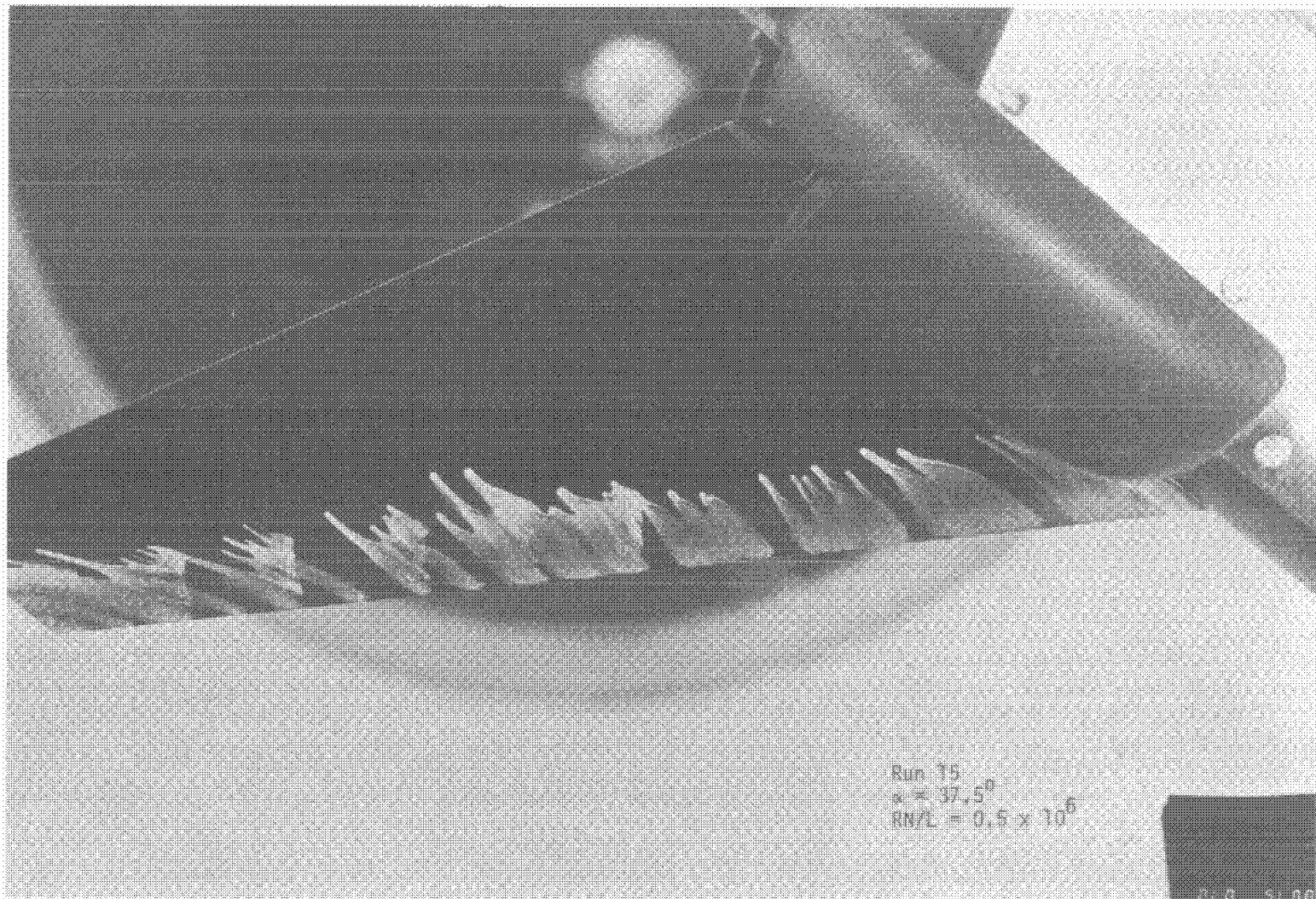


Figure 22. OIL FLOW

Run 15
 $\alpha = 37.5^\circ$
 $RN/L = 0.5 \times 10^6$

44

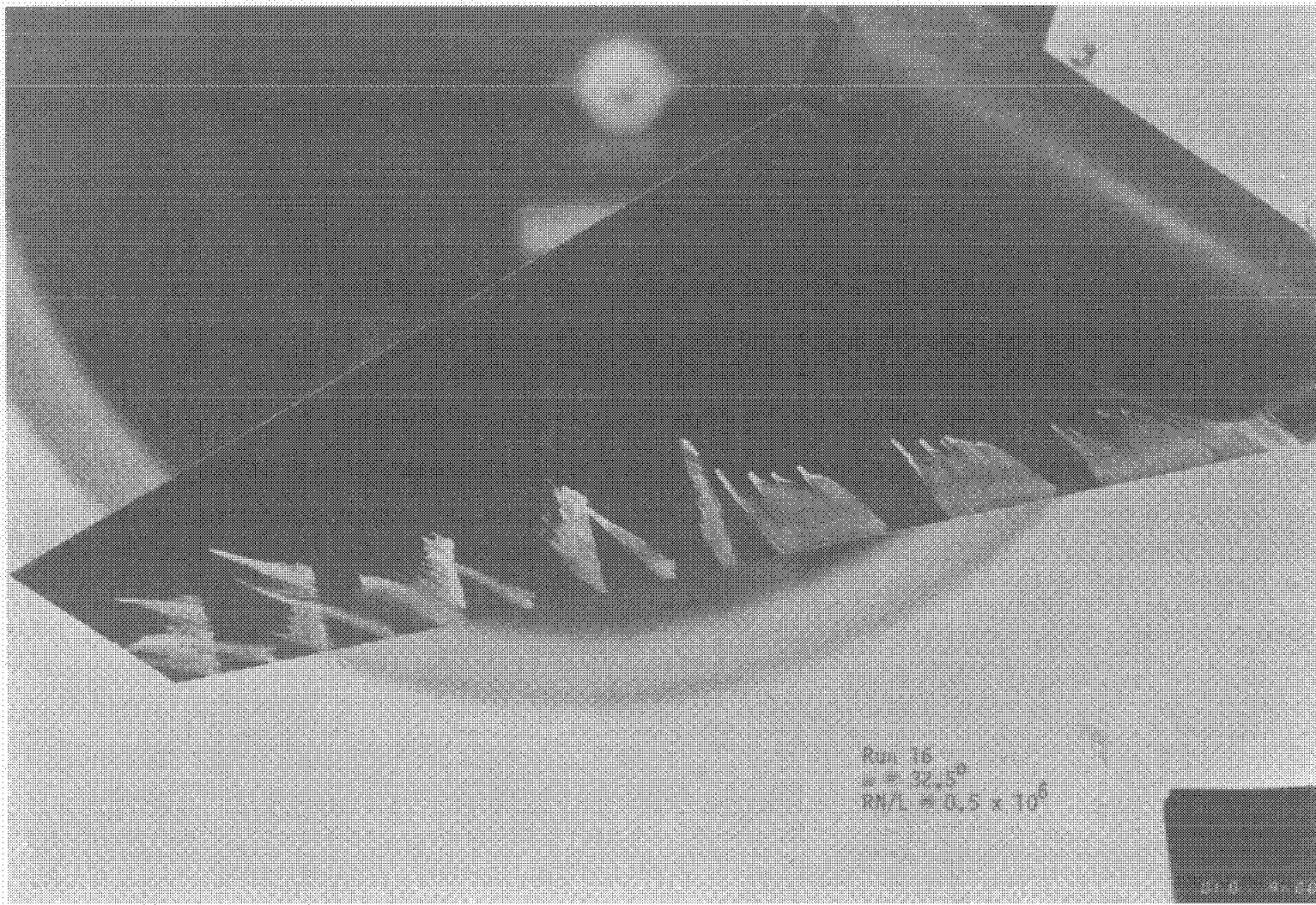


Figure 23. Oil Flow

45

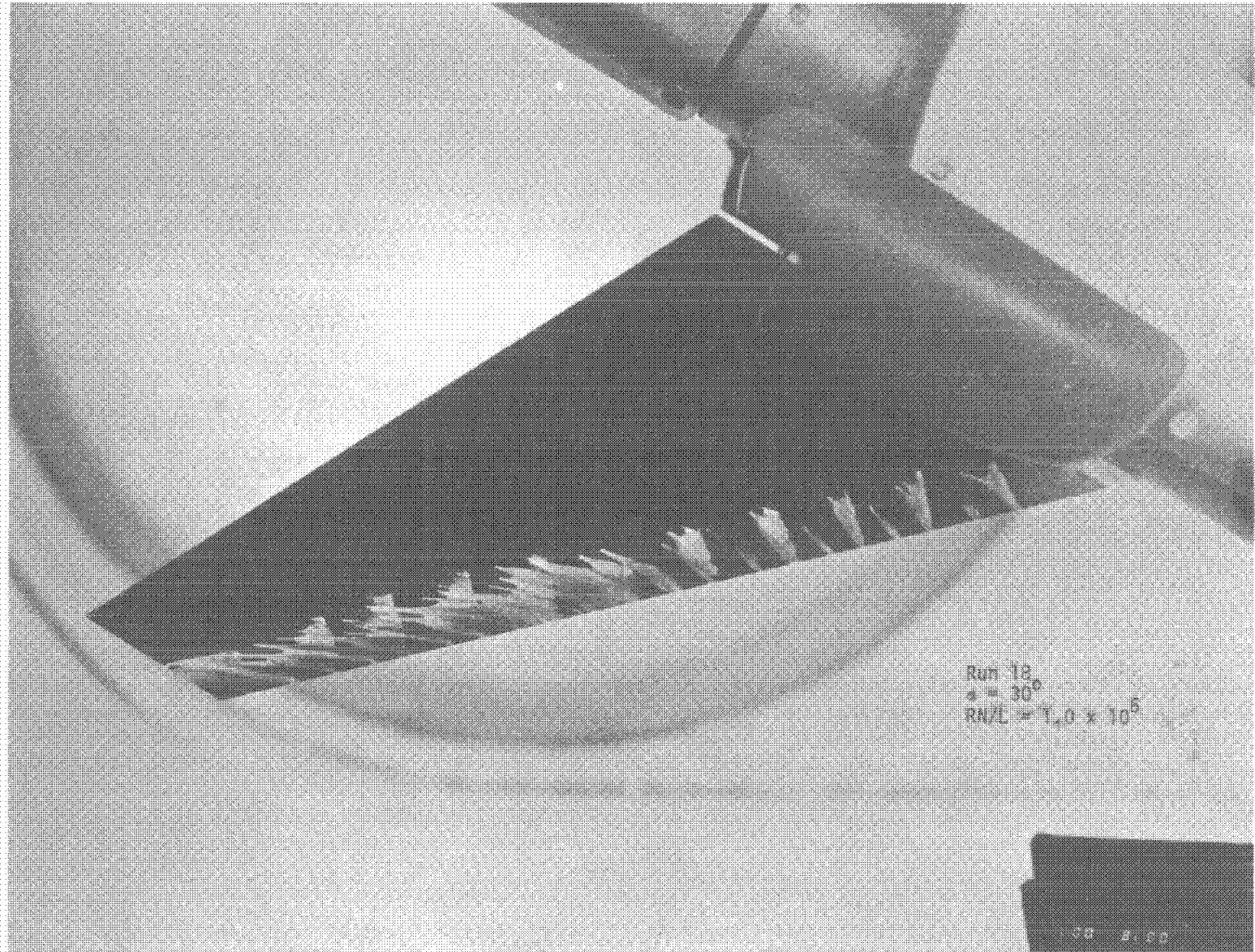


Figure 24. Oil Flow

46

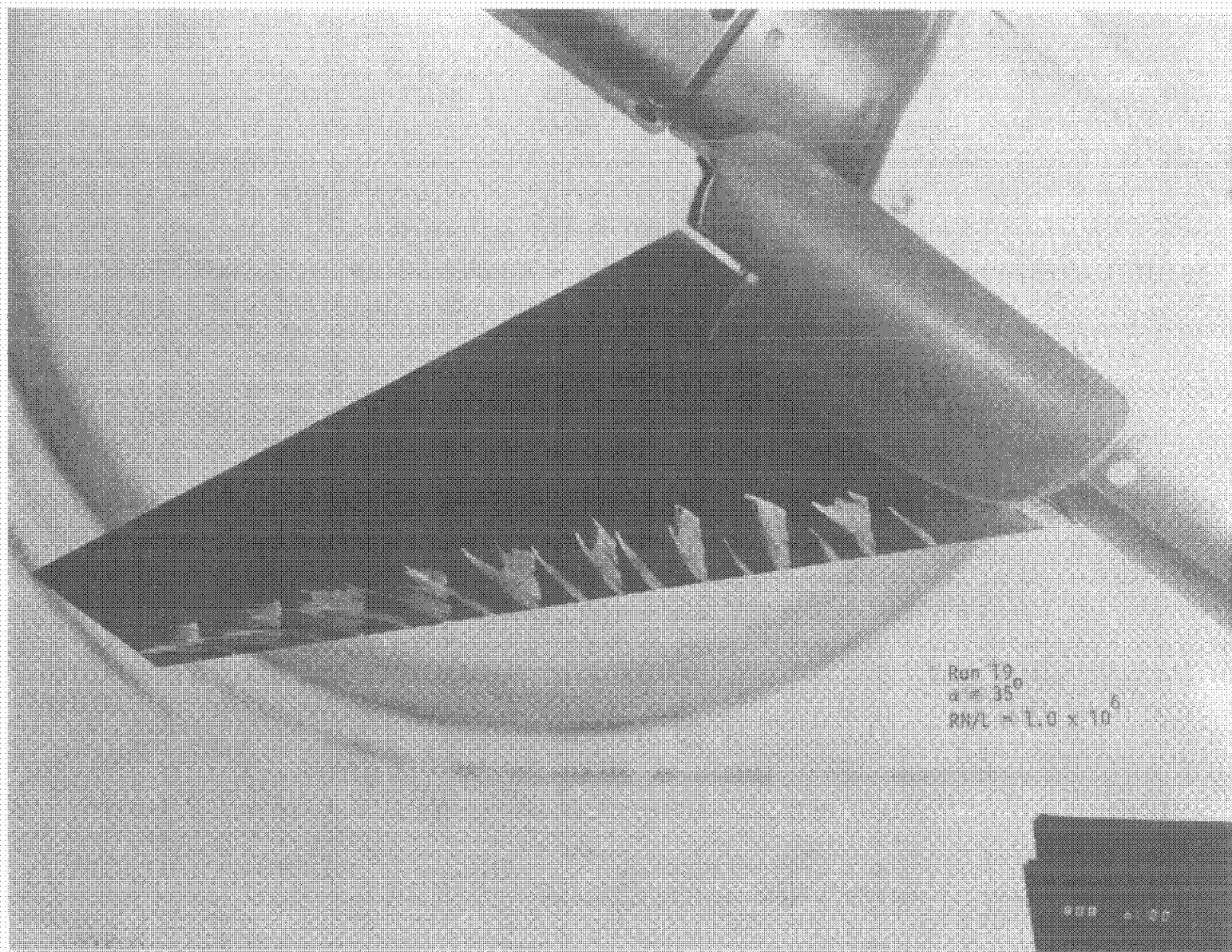


Figure 25. Oil Flow

47

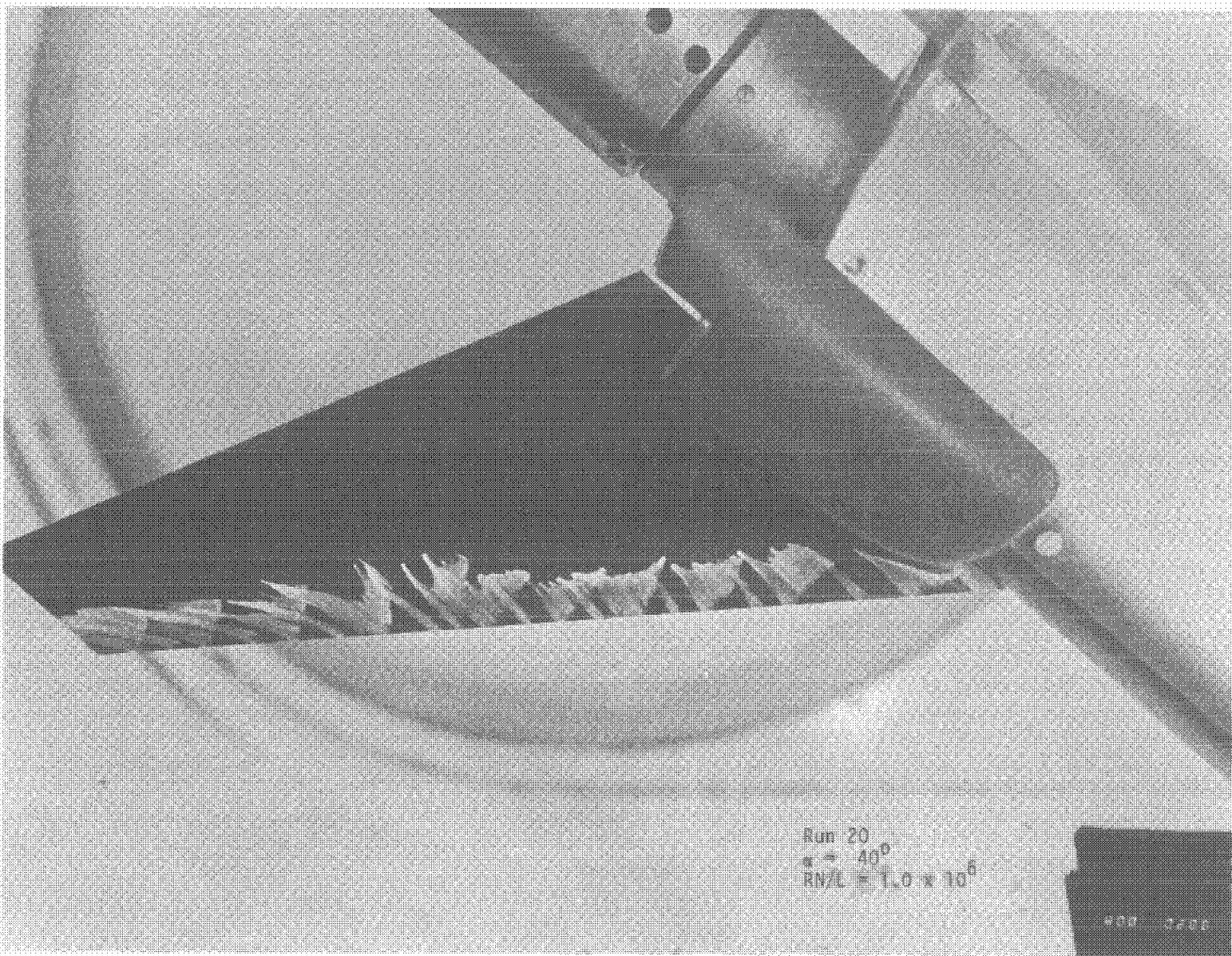


Figure 26. 011 Flow

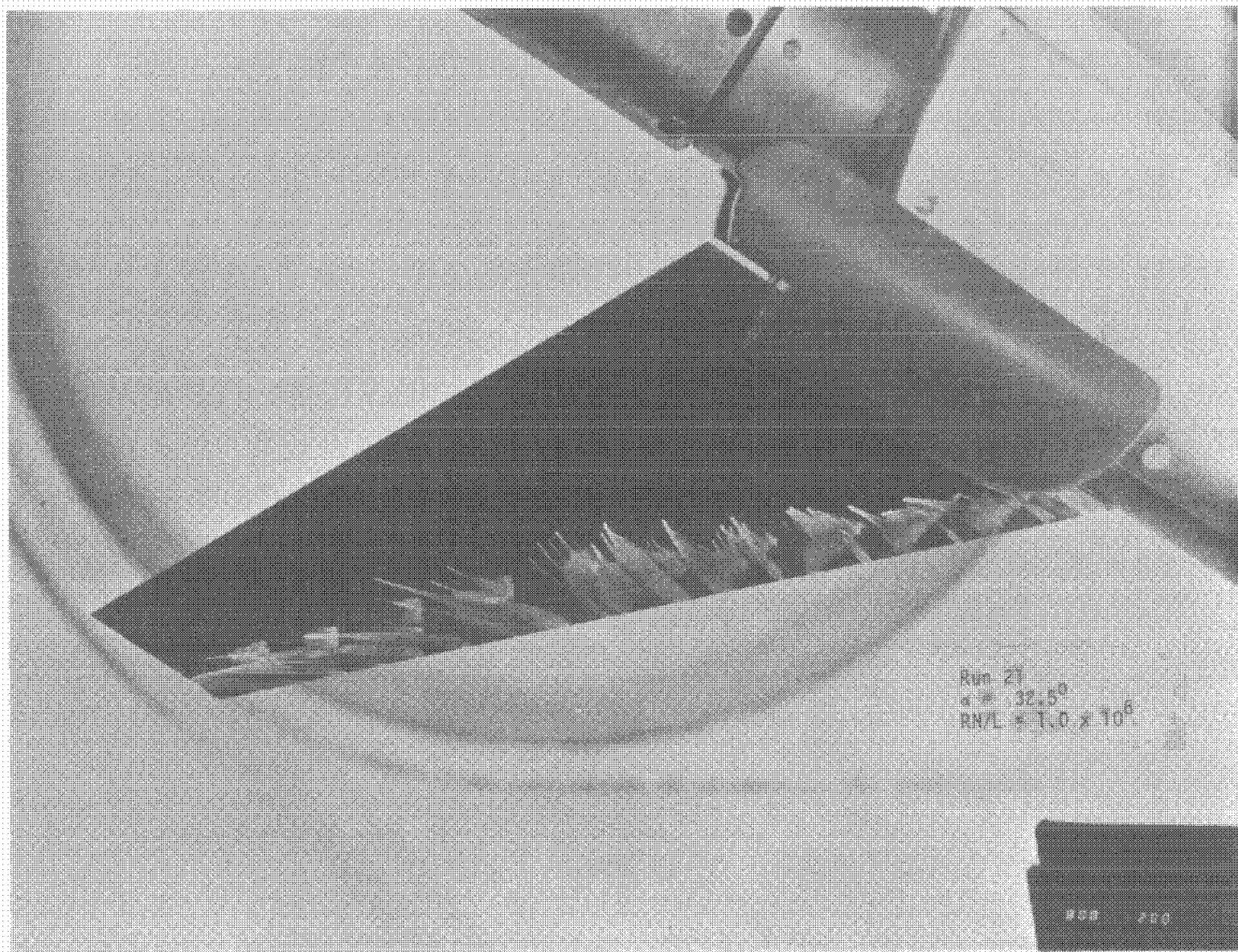


Figure 27. Of1 Flow

64

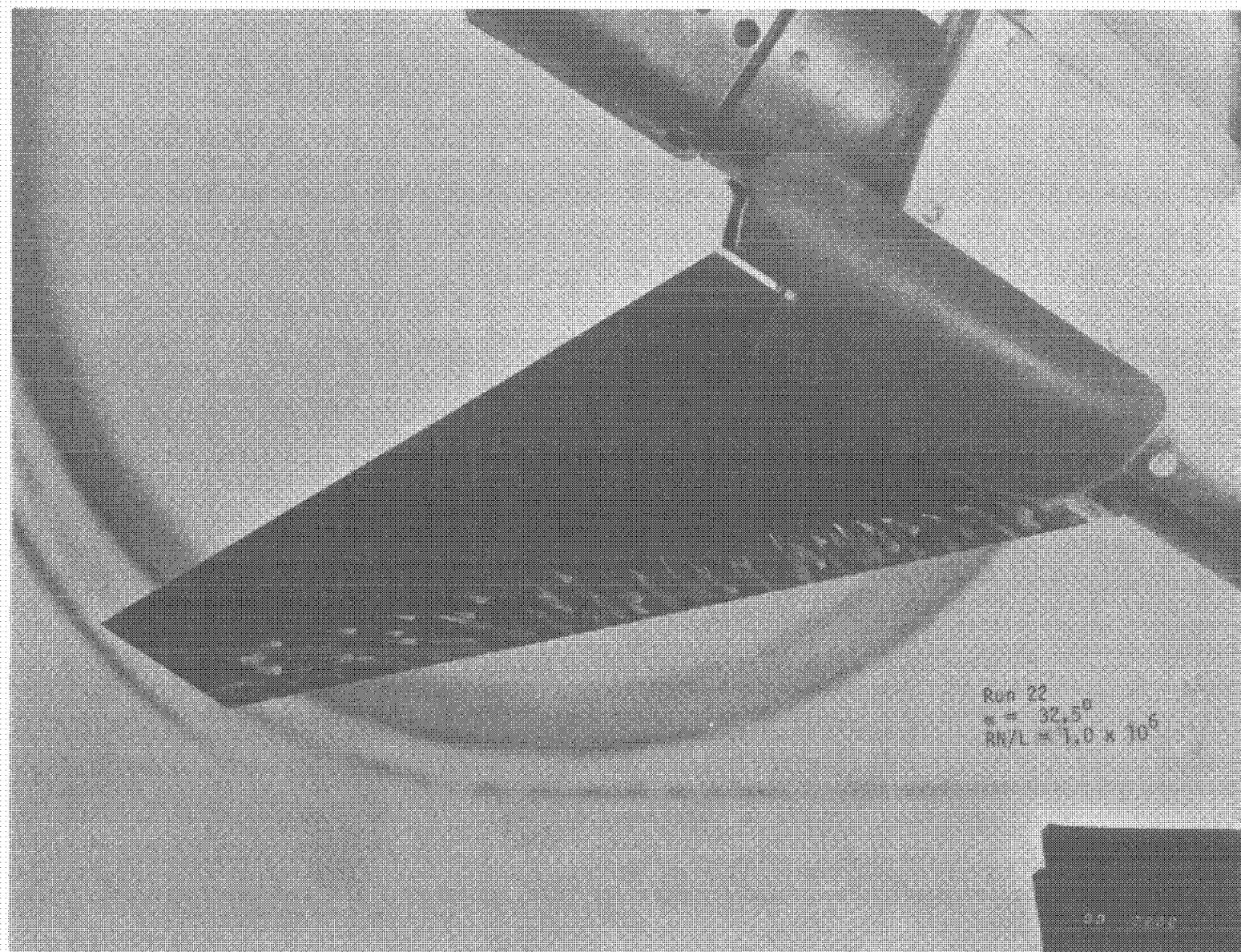


Figure 28. Oil Flow

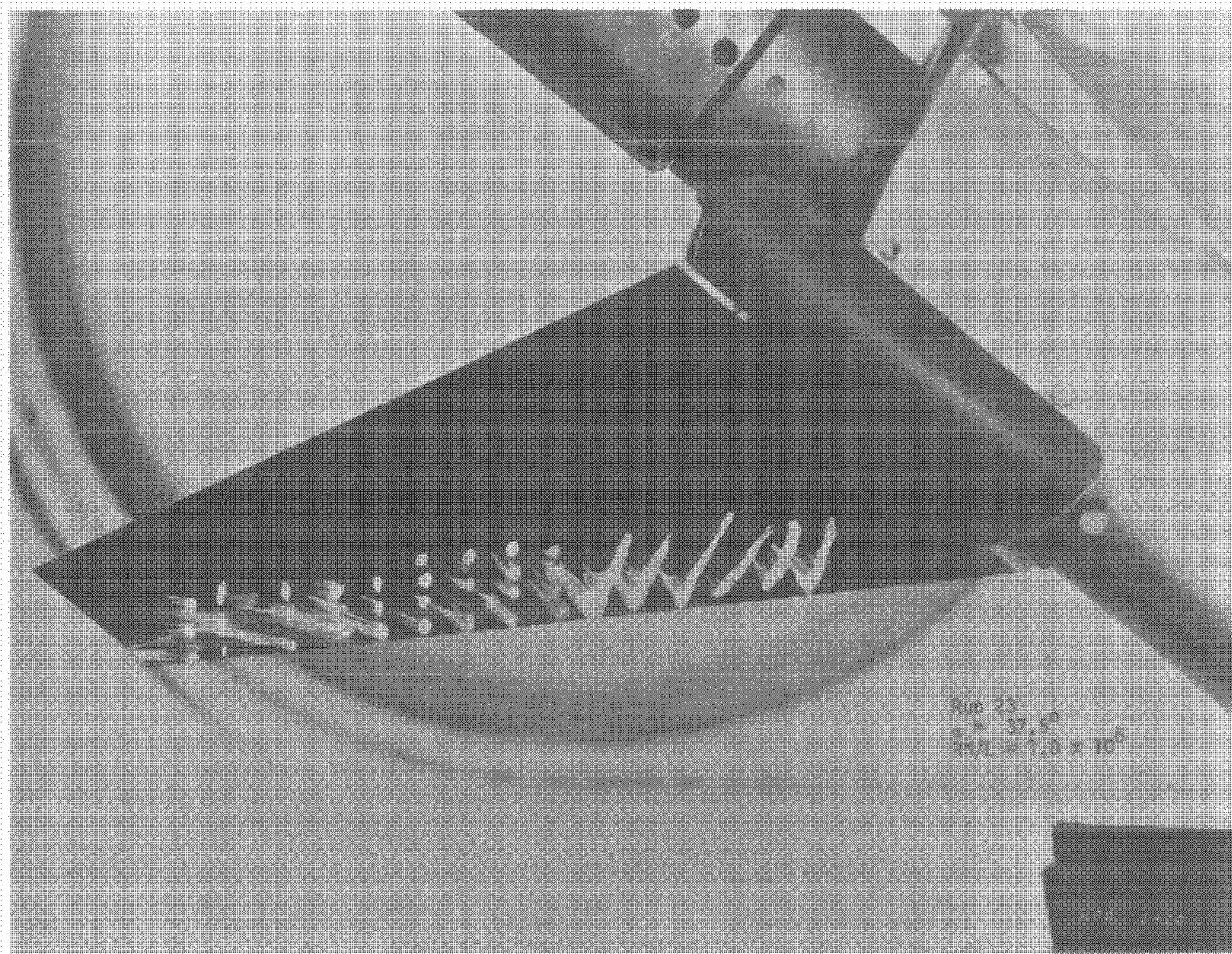


Figure 29. Of1 Flow

51

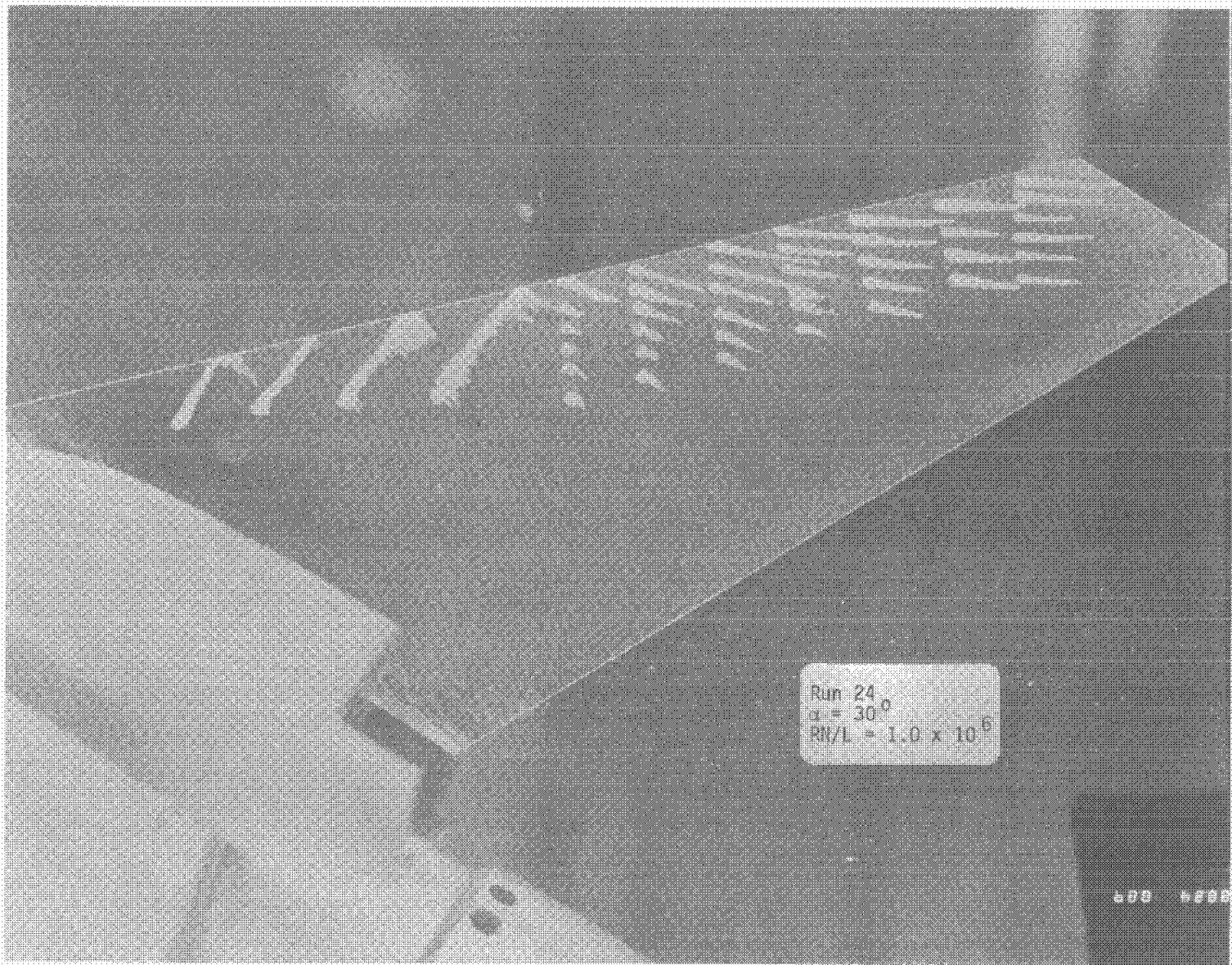


Figure 30. Oil flow

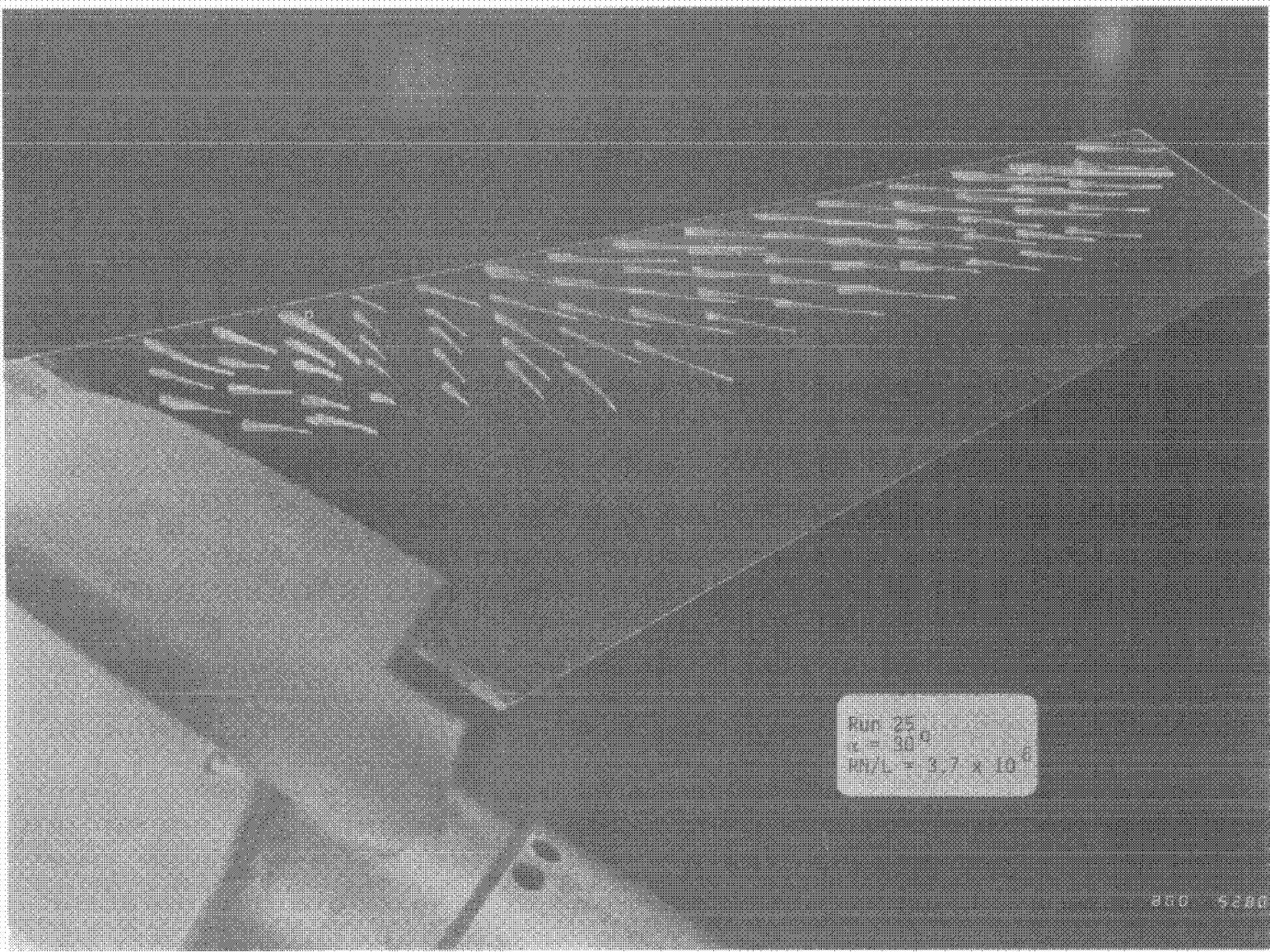


Figure 31. Oil Flow

53

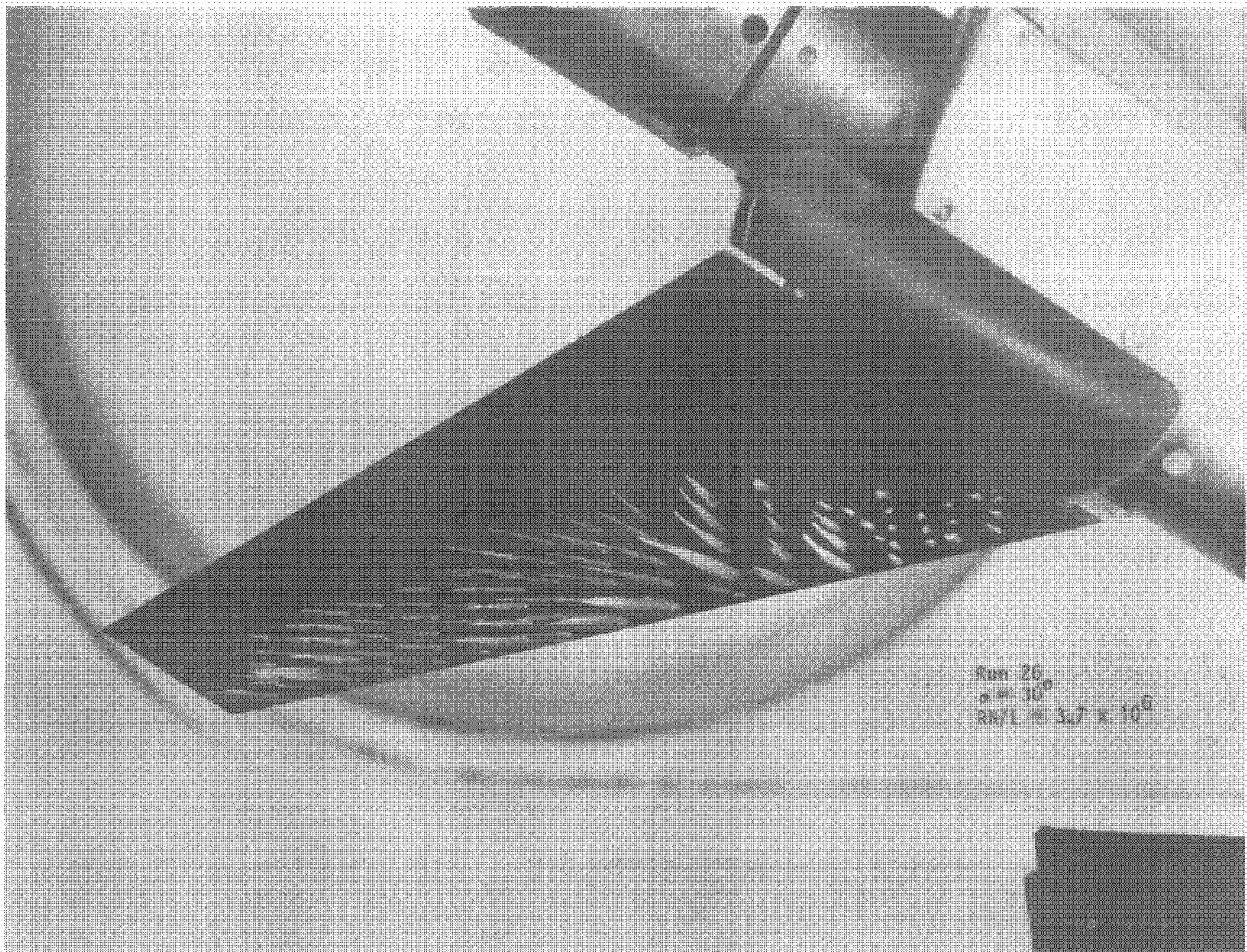


Figure 32. Oil Flow

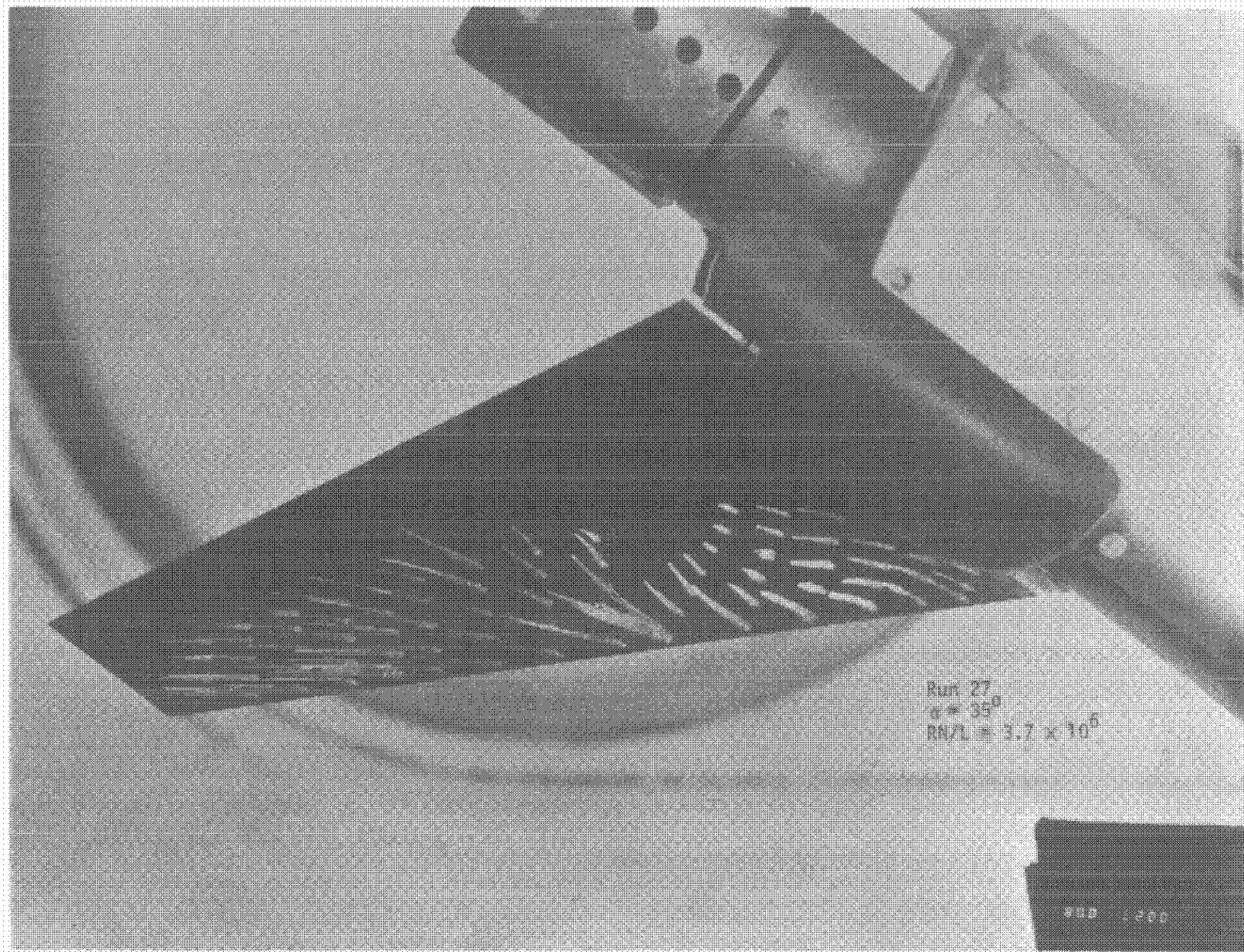


Figure 33. Oil Flow

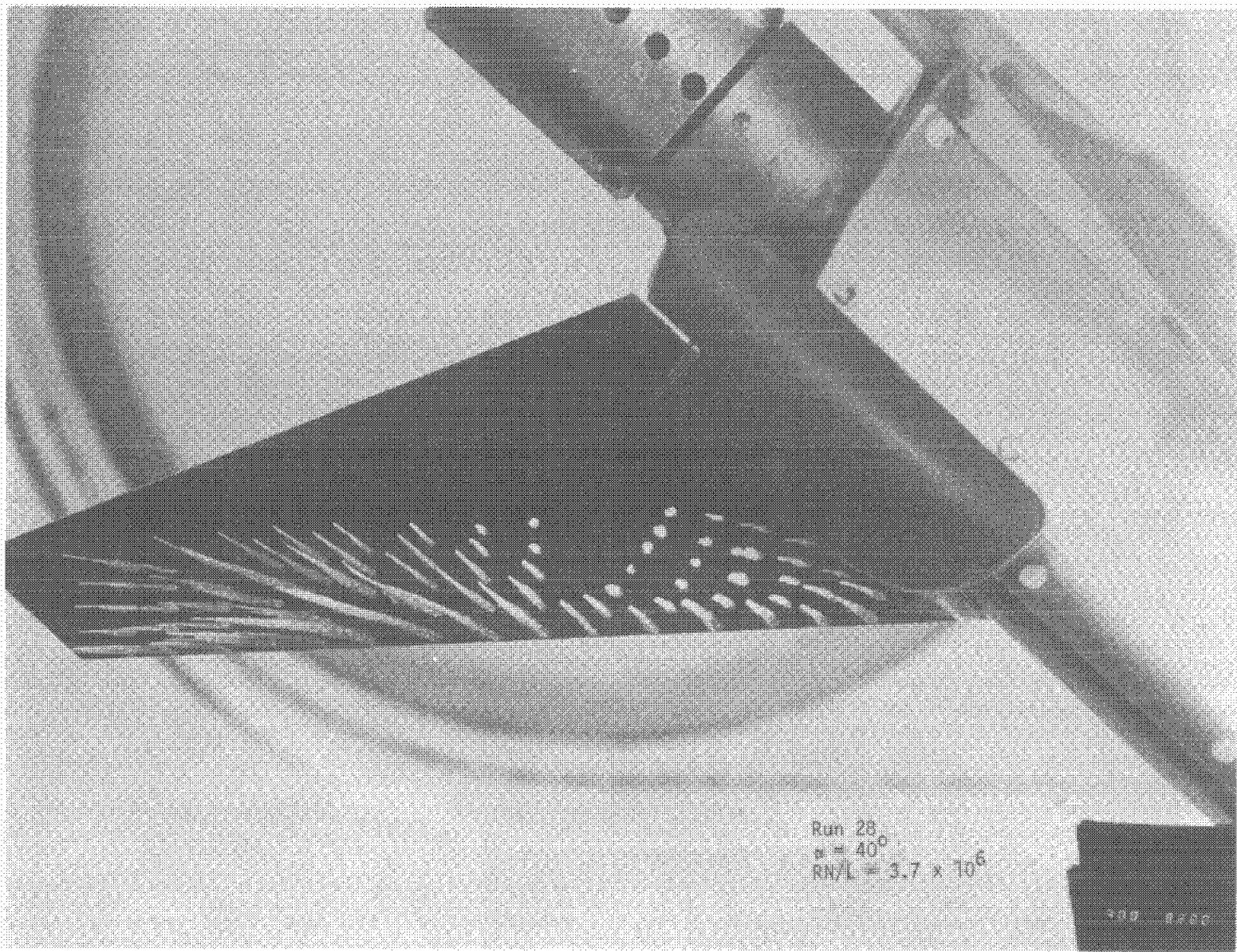


Figure 34. Oil Flow

56

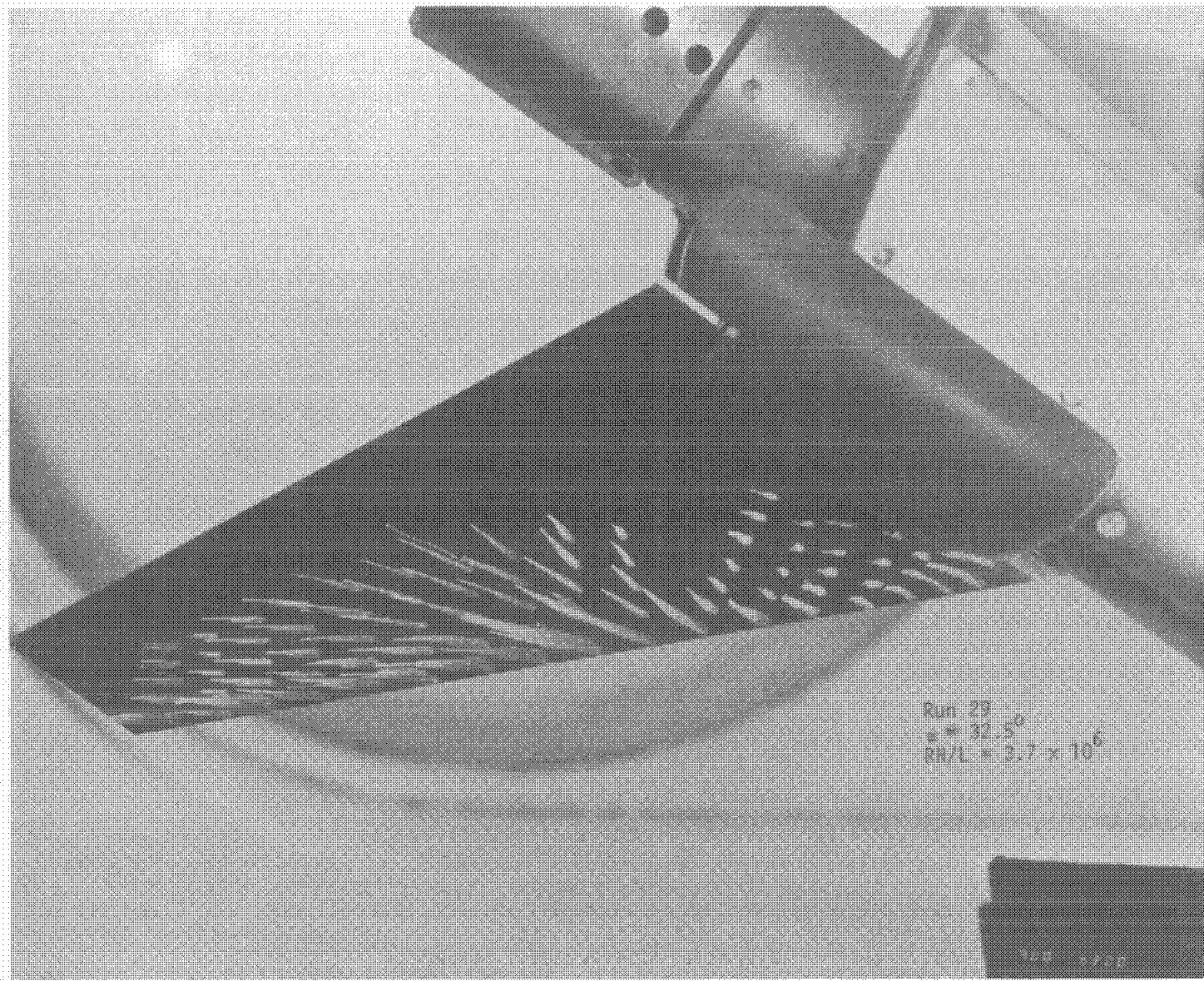


Figure 35. Oil Flow

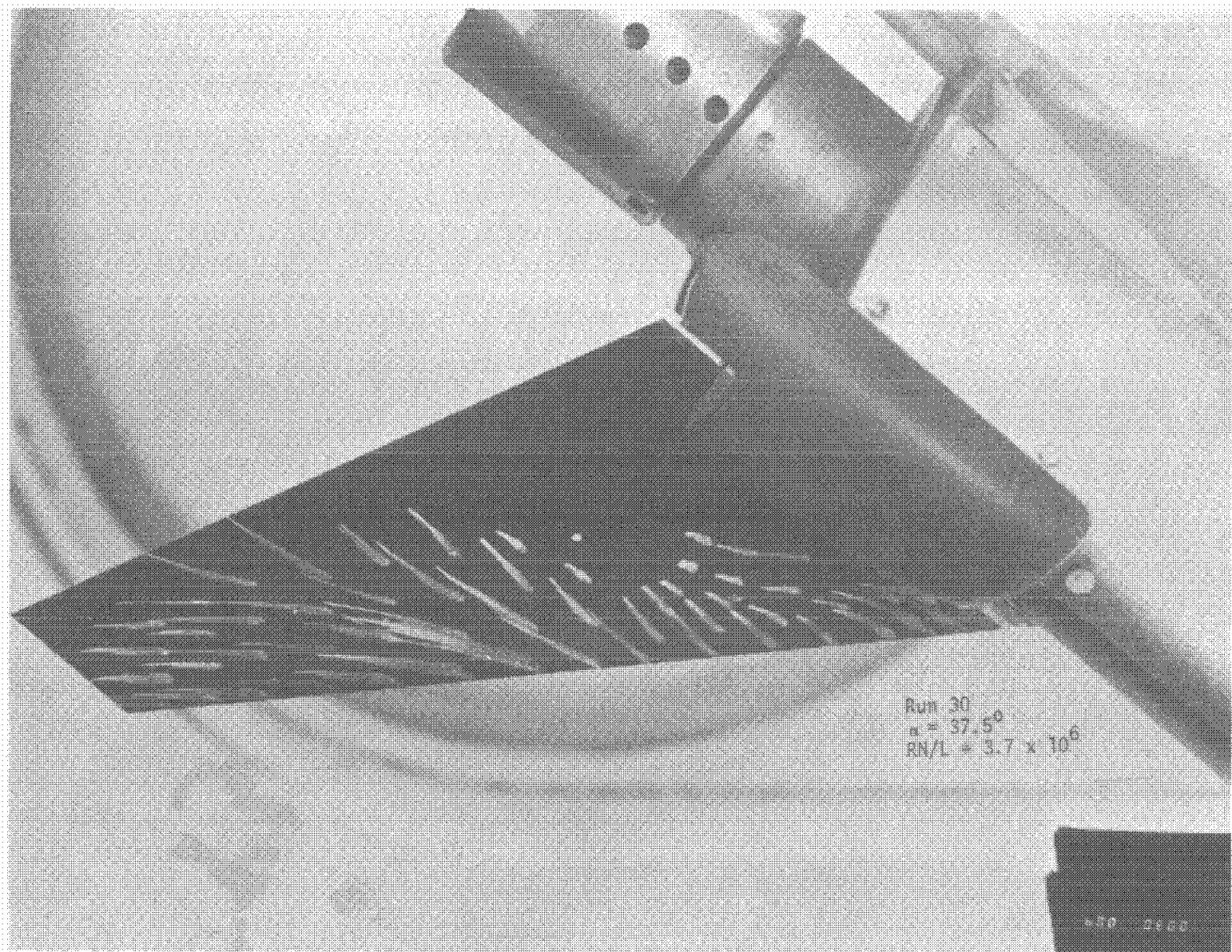


Figure 36. Oil Flow

58

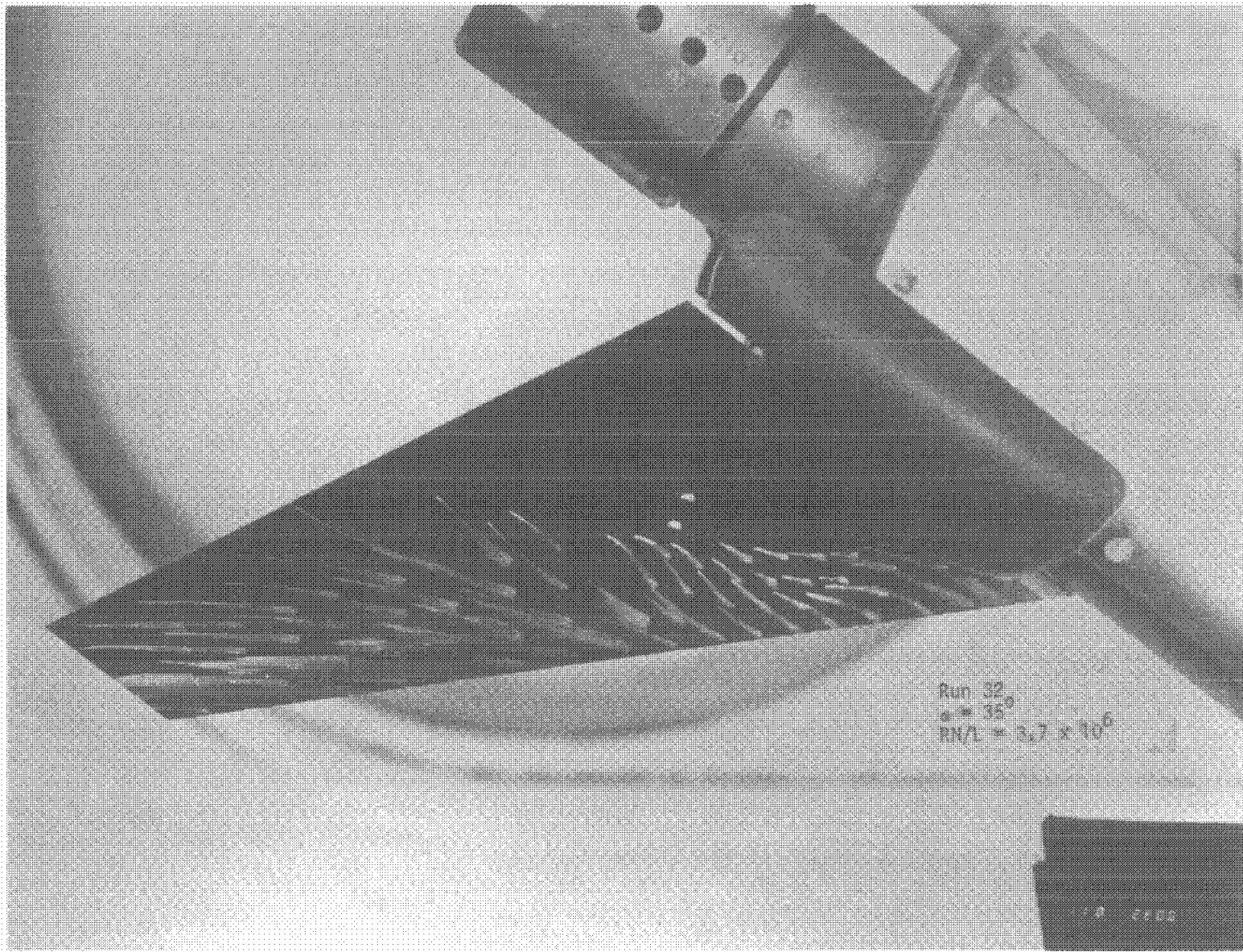


Figure 37. Oil Flow

59

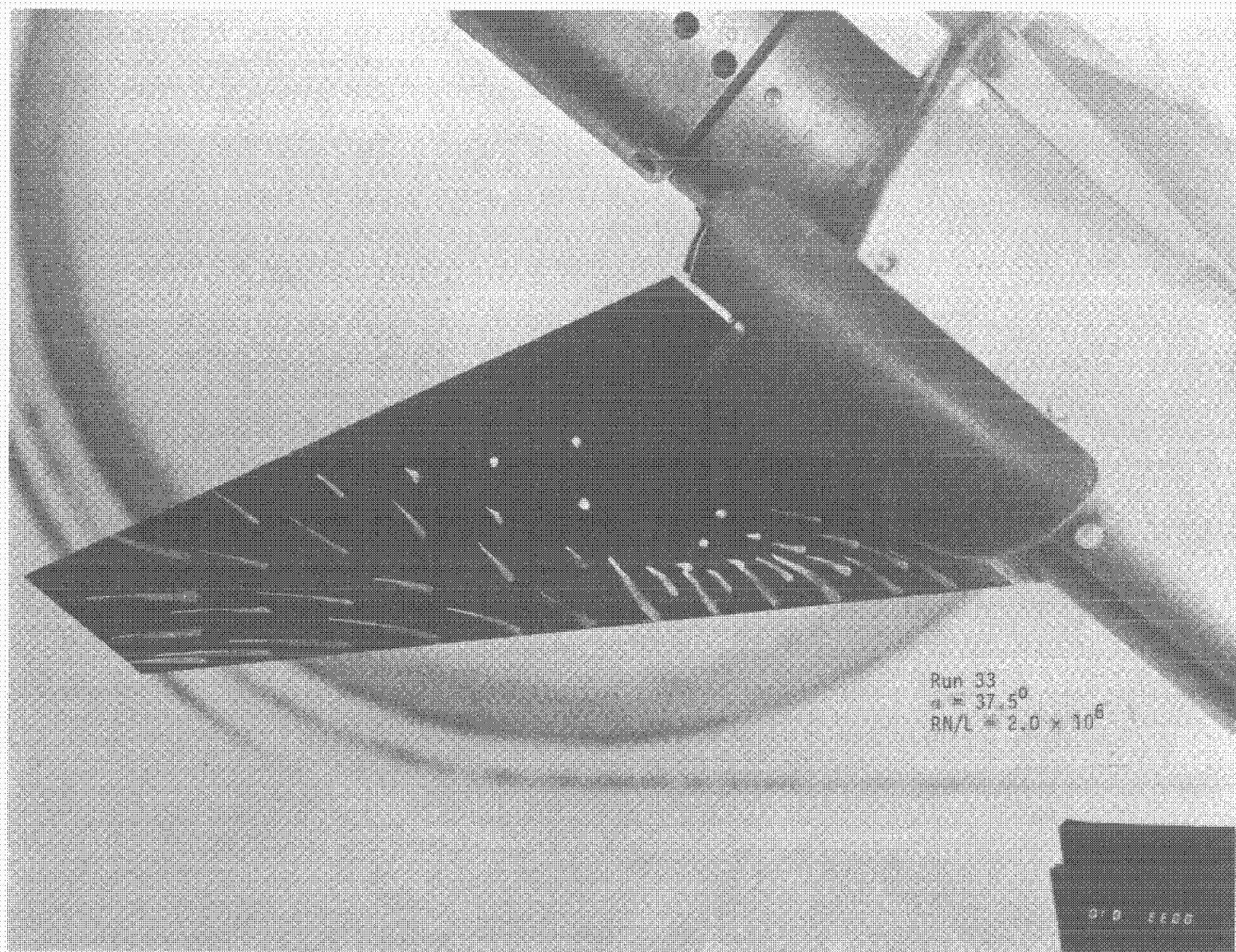


Figure 38. Oil Flow

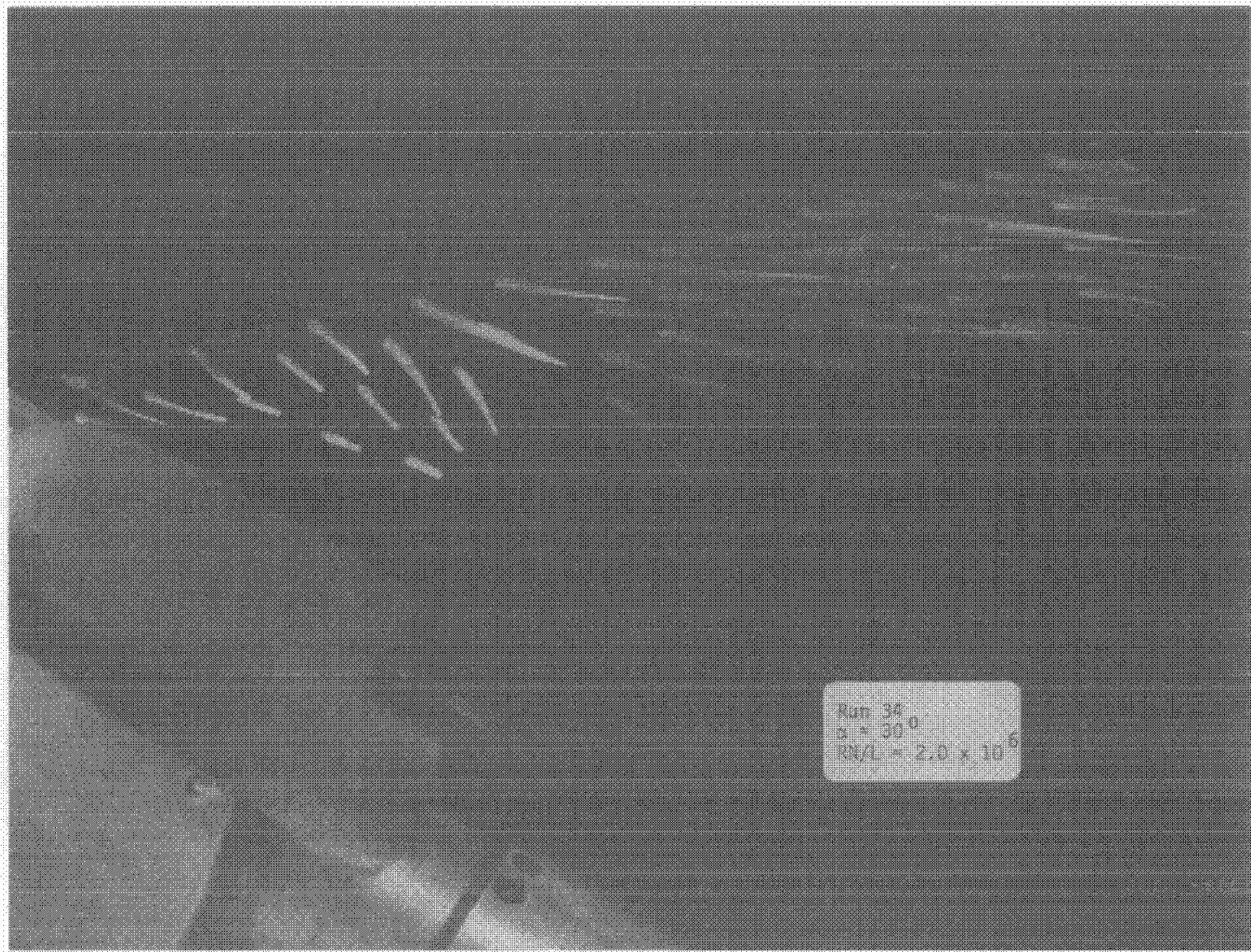


Figure 39. Oil Flow

19

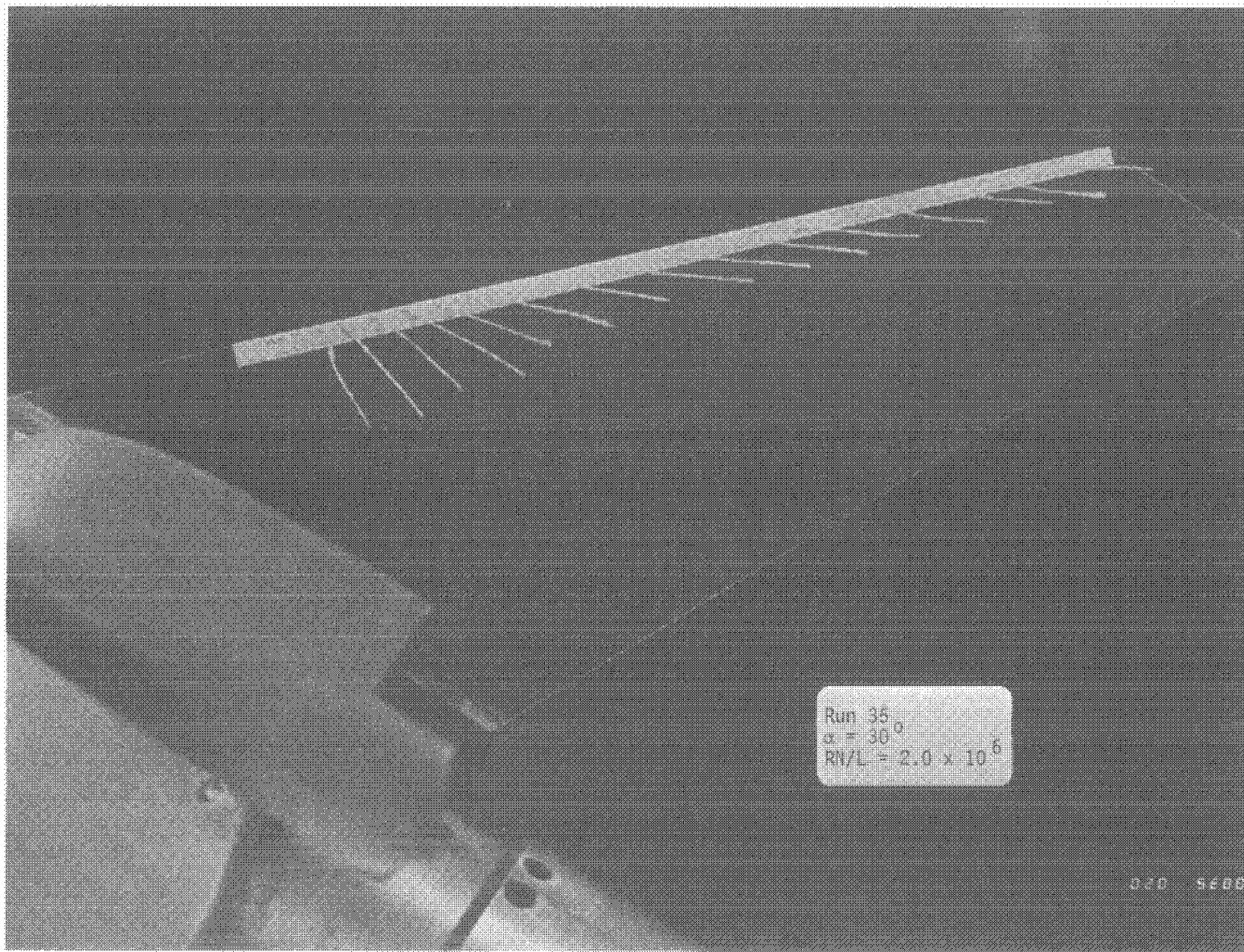


Figure 40. Tufts

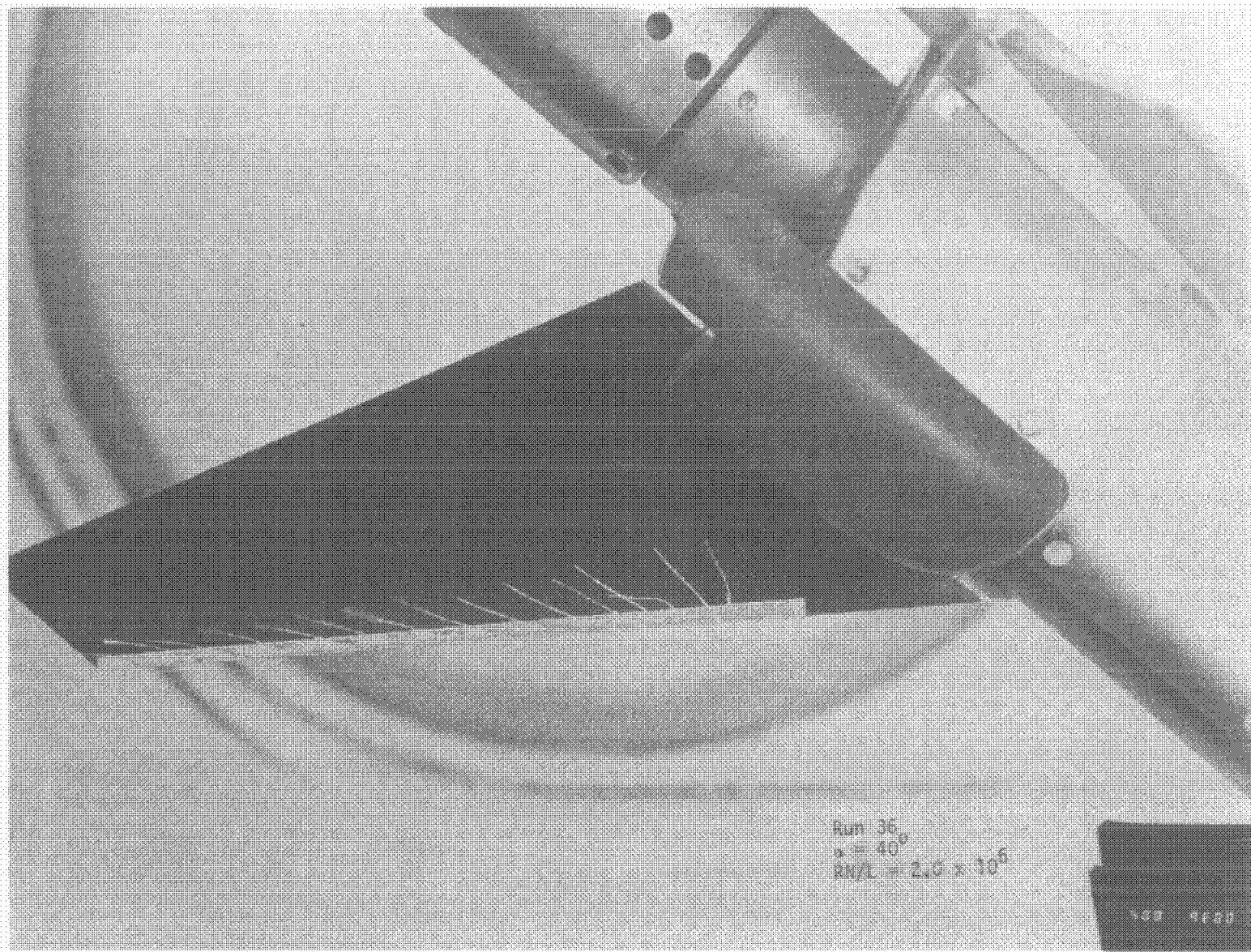


Figure 41. Tufts

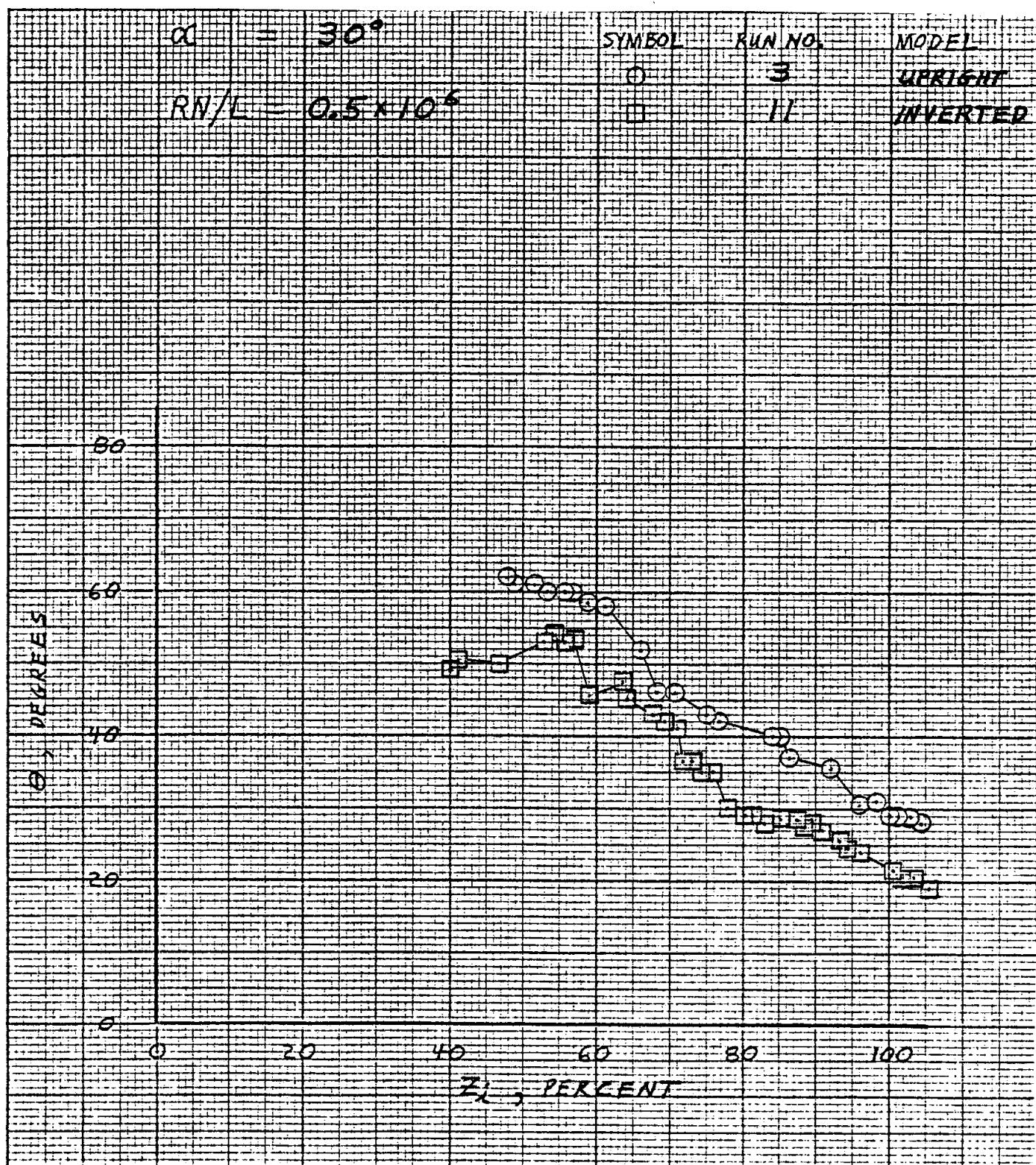


Figure 42. Flow Direction

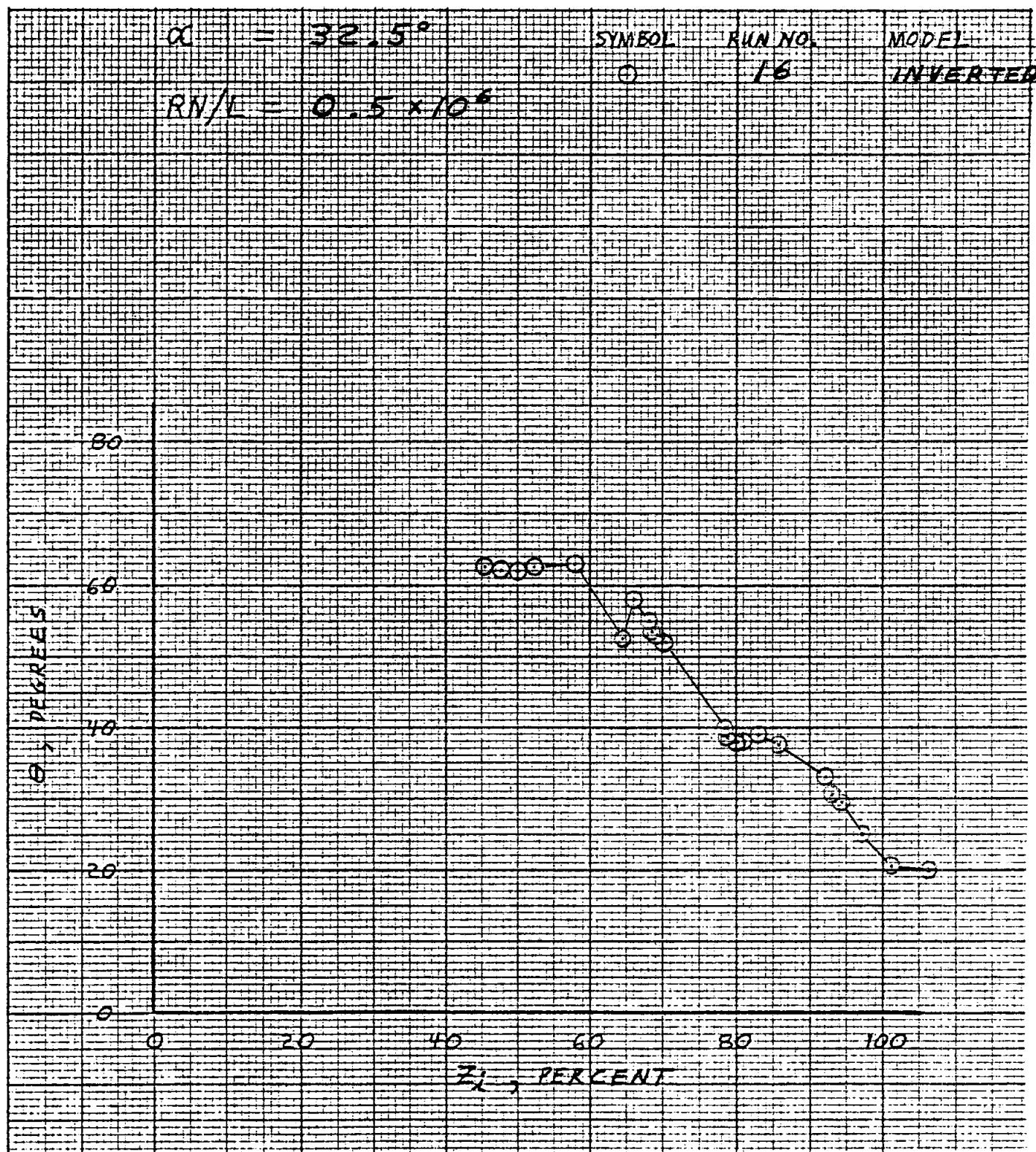


Figure 43. Flow Direction

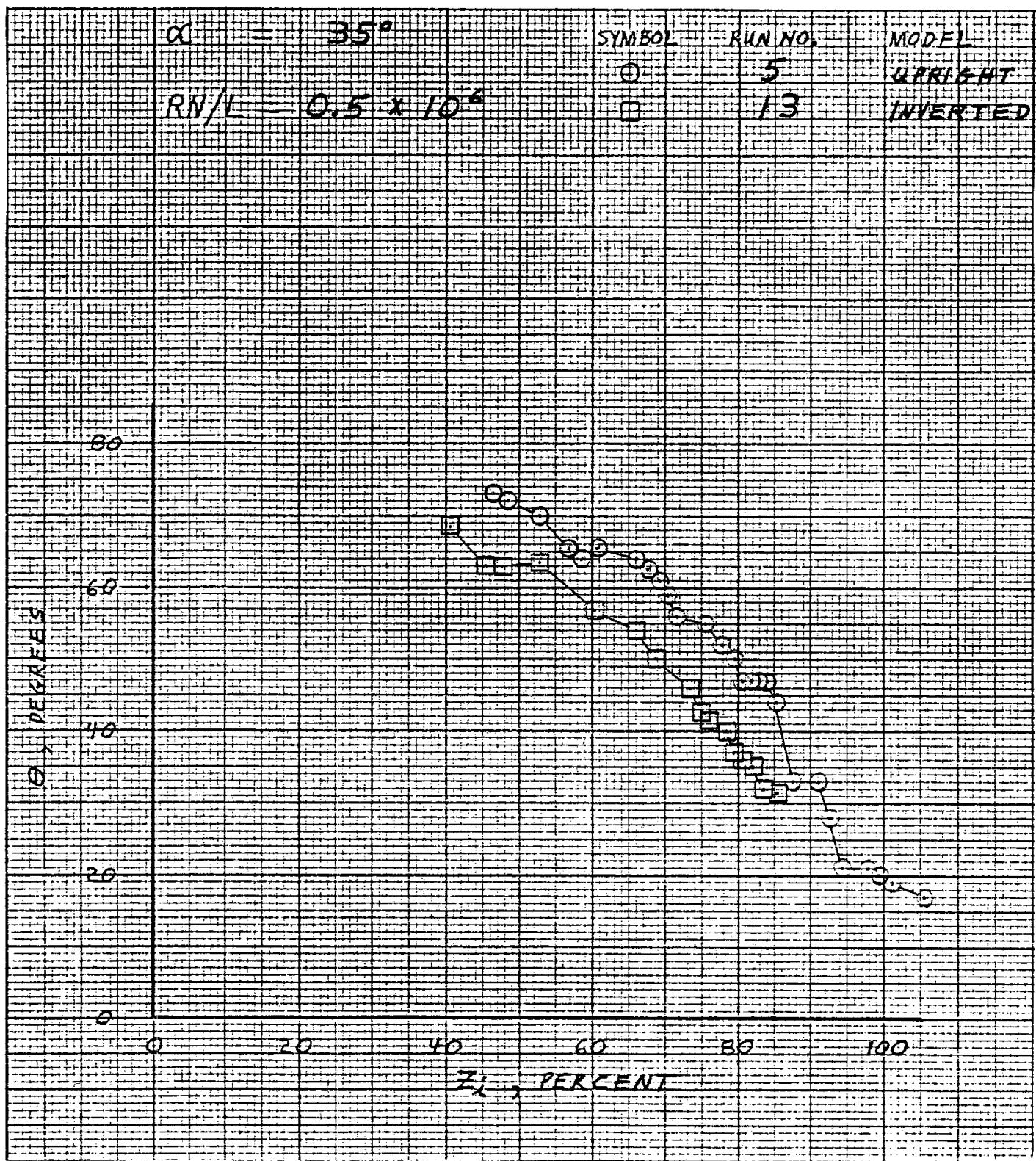


Figure 44. Flow Direction

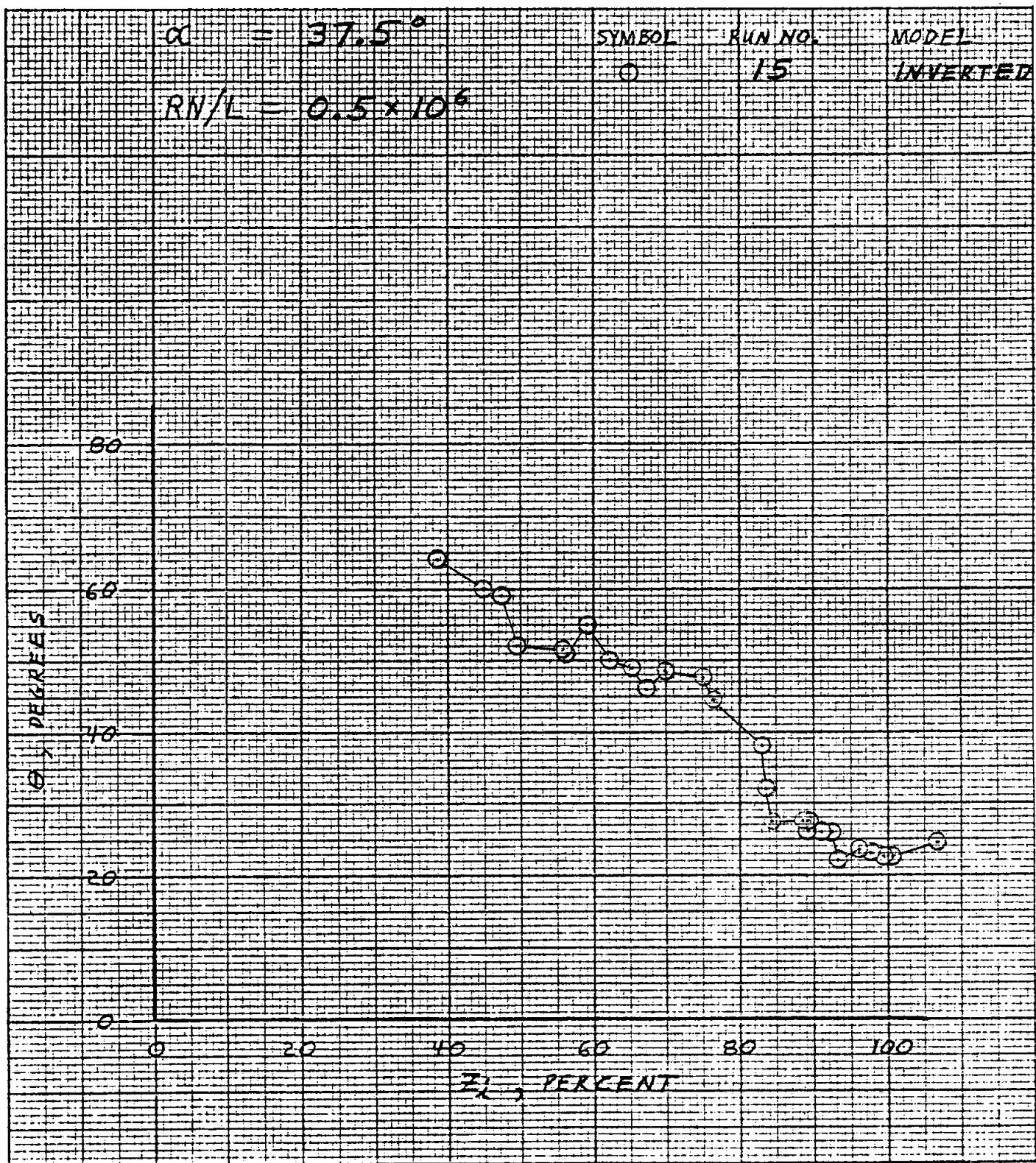


Figure 45. Flow Direction

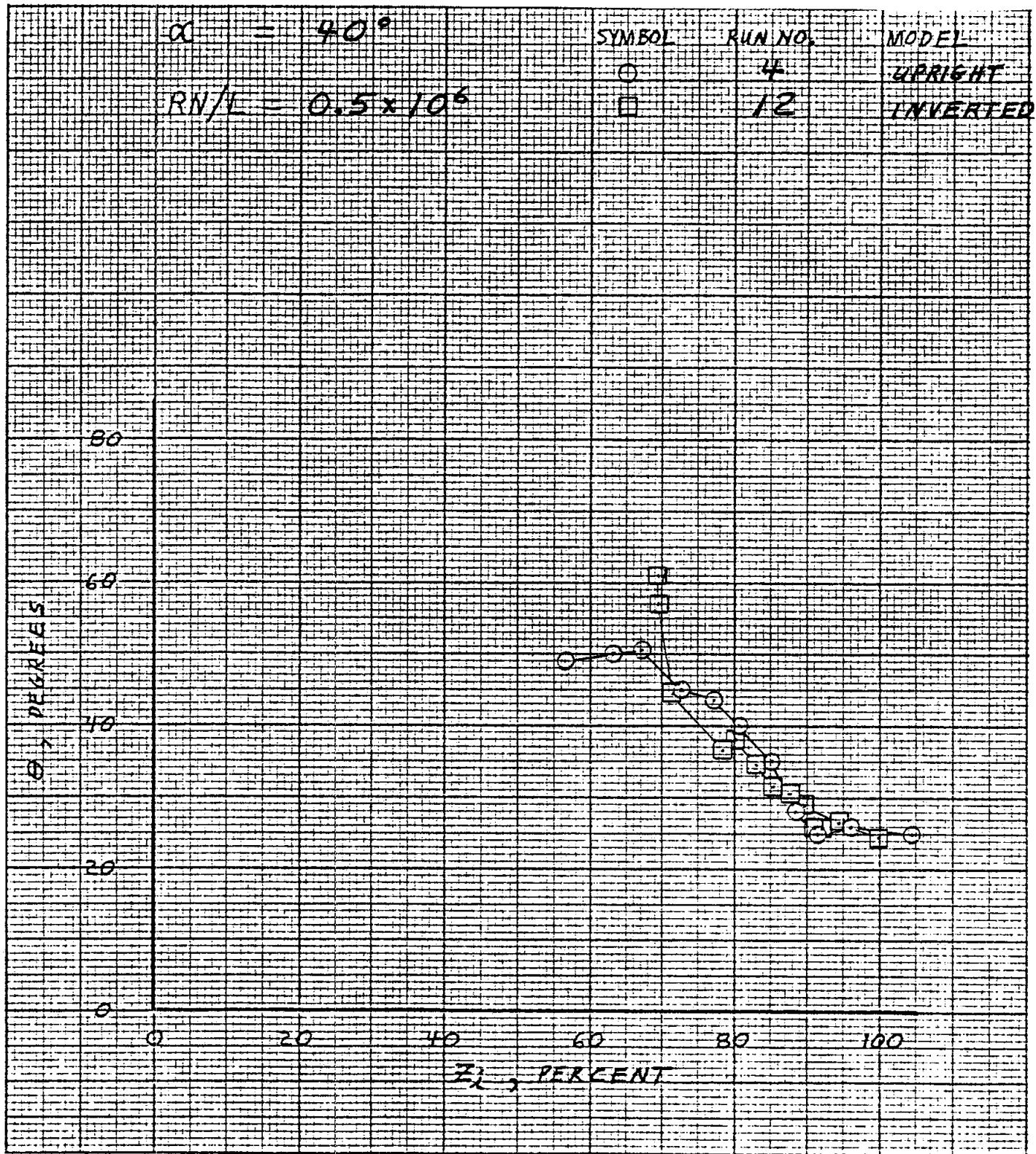


Figure 46. Flow Direction

$\alpha = 30^\circ$

$RN/L = 1.0 \times 10^6$

SYMBOL	RUN NO.	MODEL
○	18	INVERTED
□	24	ROLLED 90° TO RIGHT

80

60

40

20

0

0 20 40 60 80 100

Z_L , PERCENT

Figure 47. Flow Direction

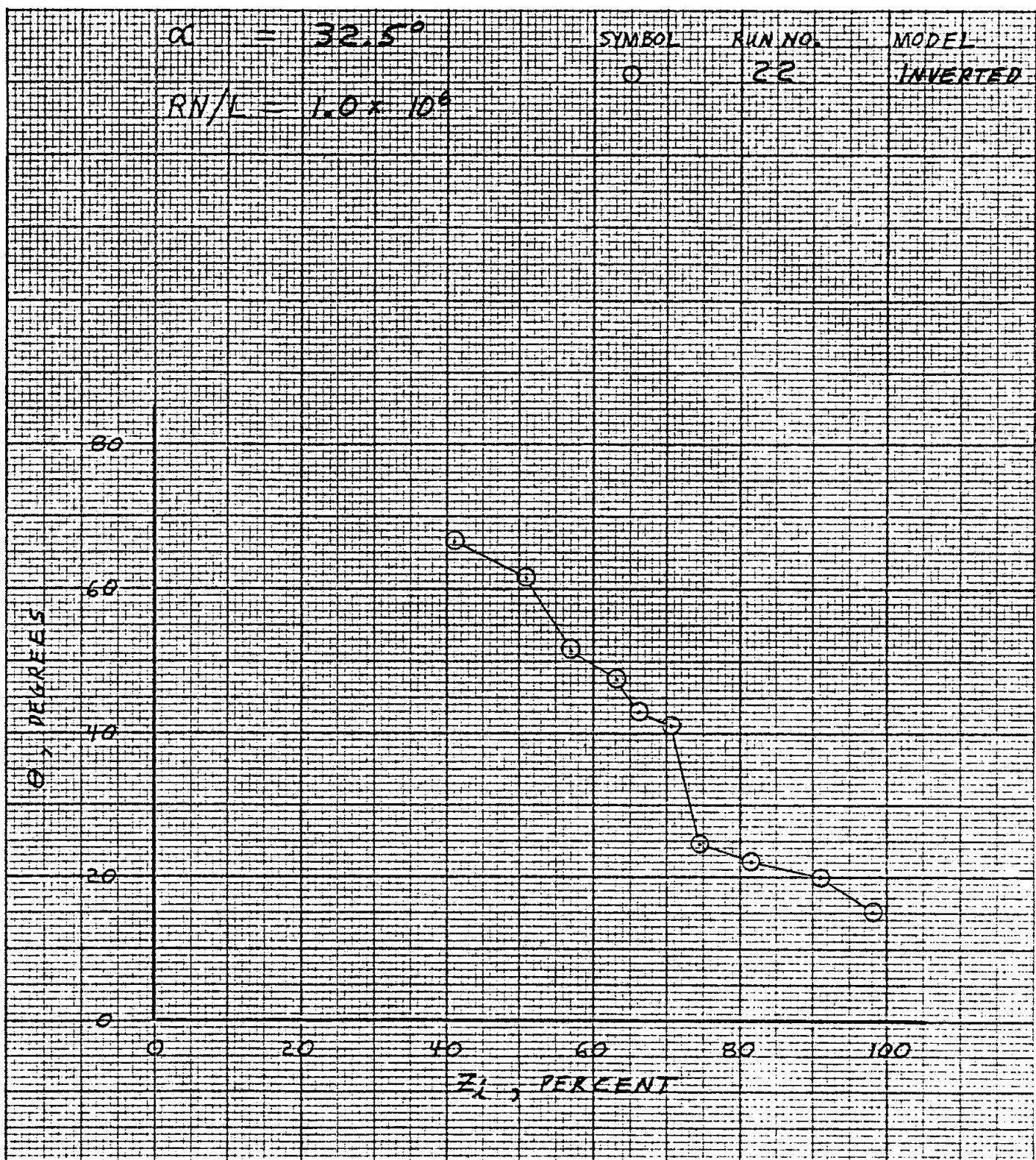


Figure 48. Flow Direction

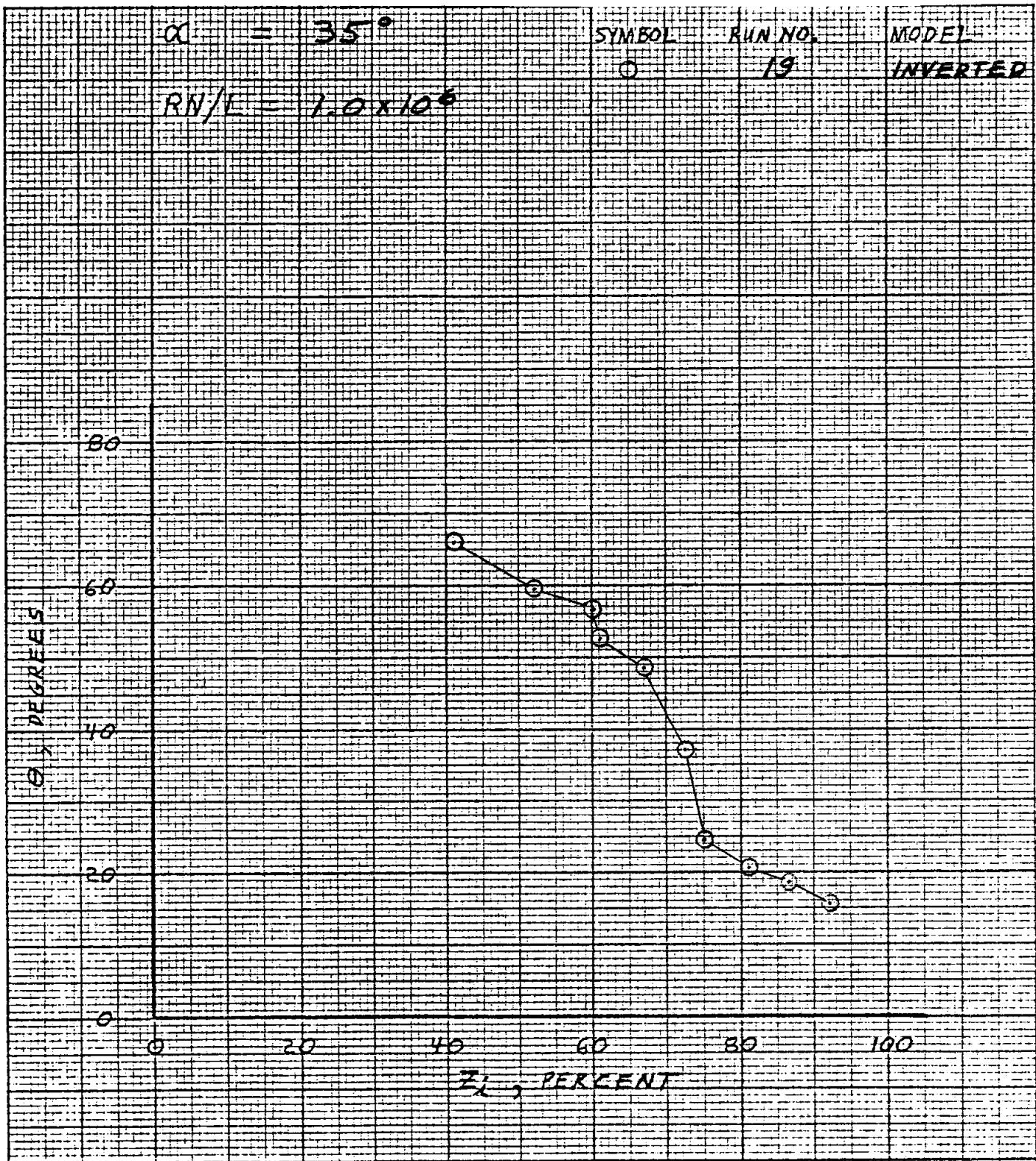


Figure 49. Flow Direction

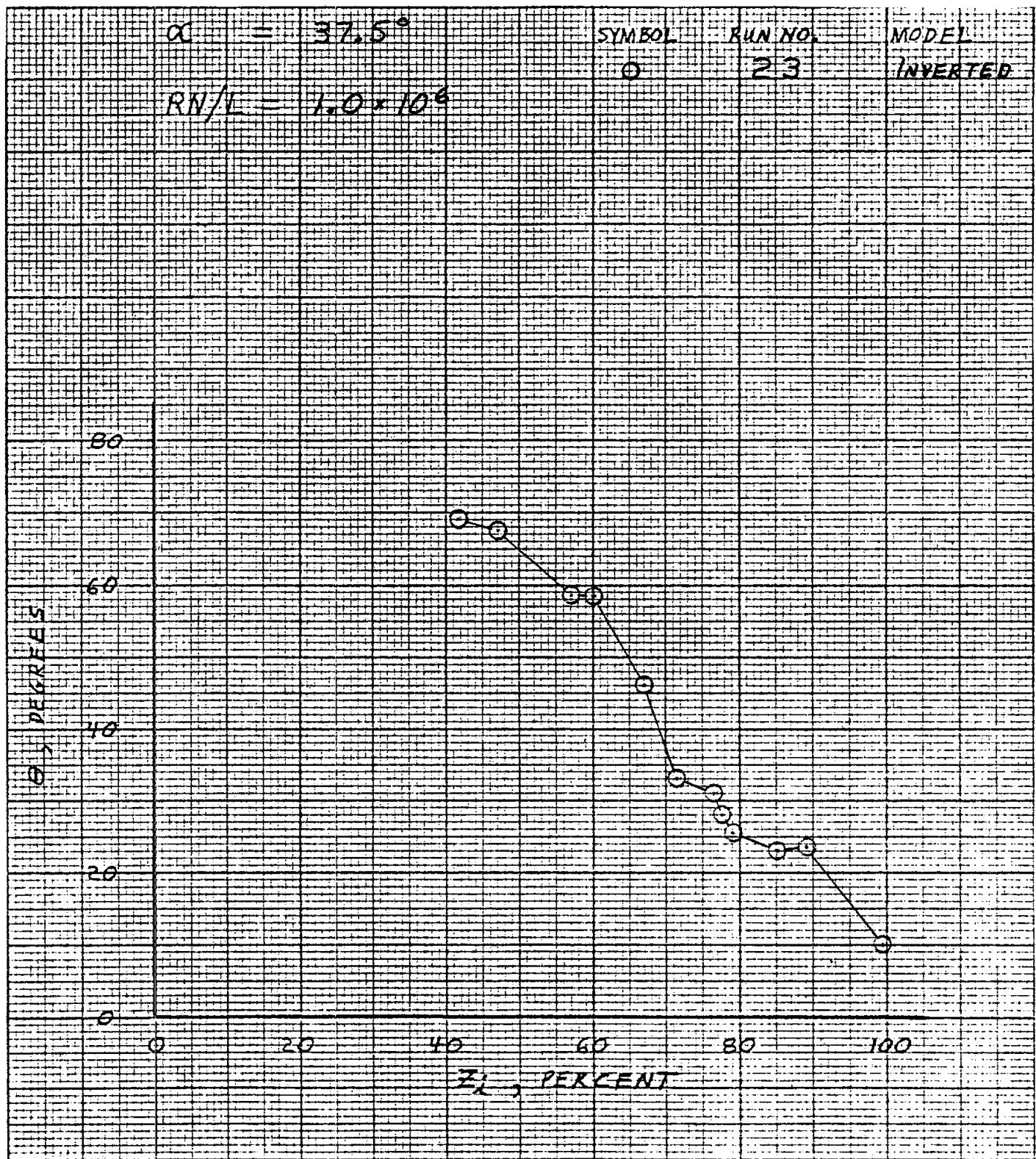


Figure 50. Flow Direction

$\alpha = 40^\circ$

$RN/L = 1.0 \times 10^6$

SYMBOL

○

RUN NO.

20

MODEL

INVERTED

80

60

40

20

0

0

20

40

60

80

100

ZL, PERCENT

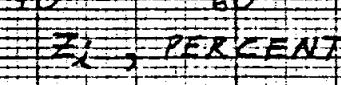


Figure 51. Flow Direction

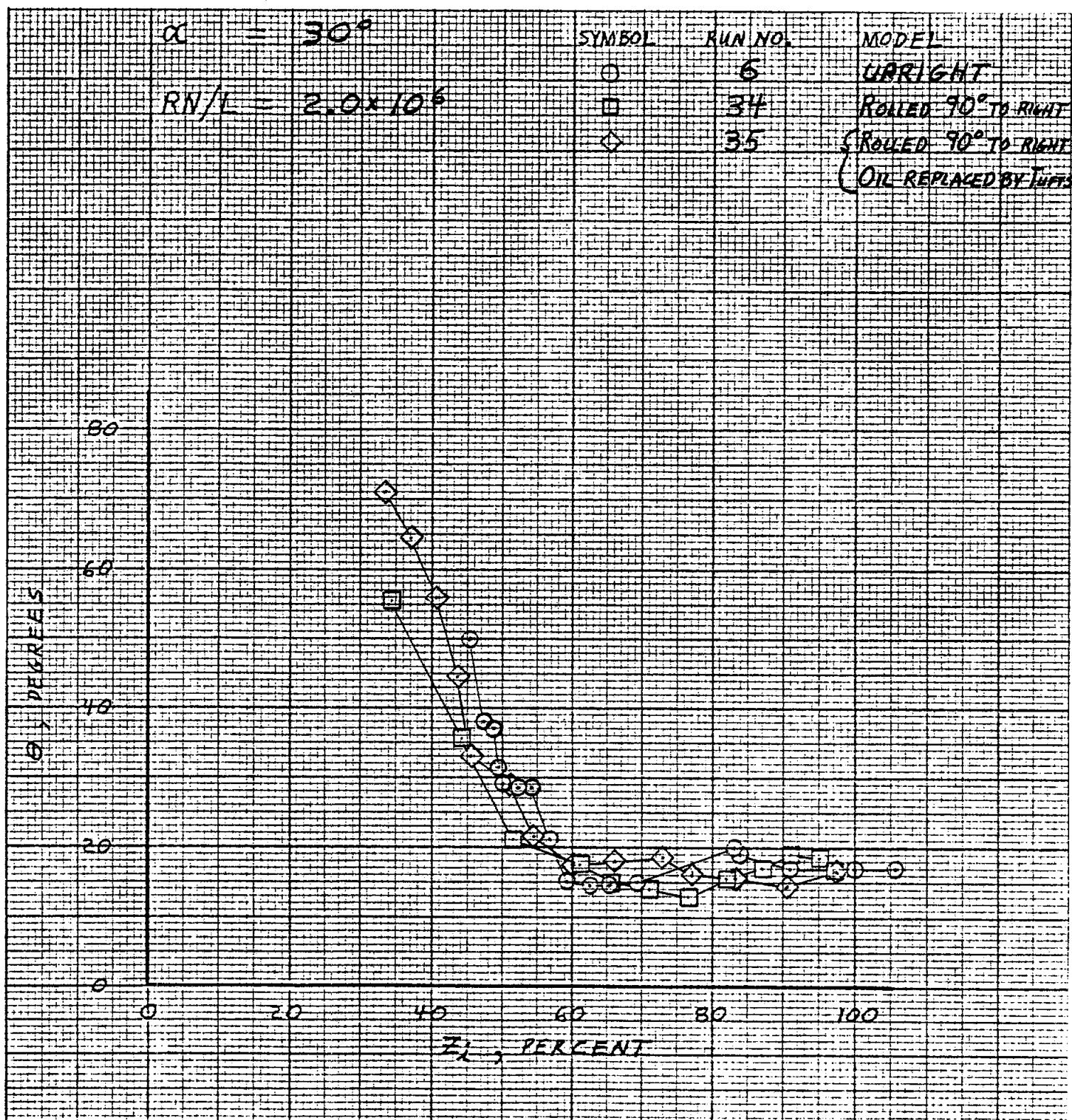


Figure 52. Flow Direction

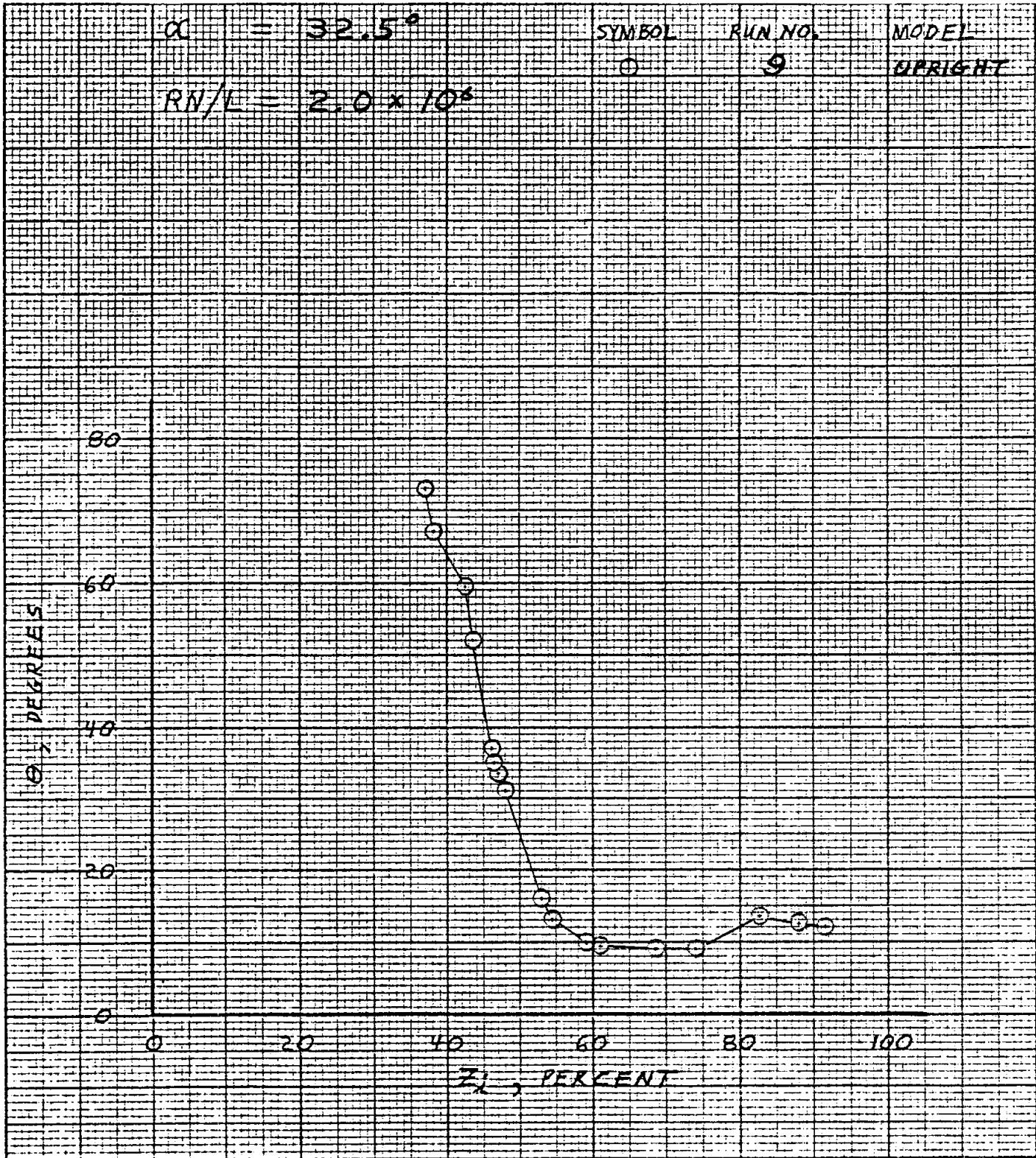


Figure 53. Flow Direction

$$\alpha = 35^\circ$$

RN/L 2.0×10^6

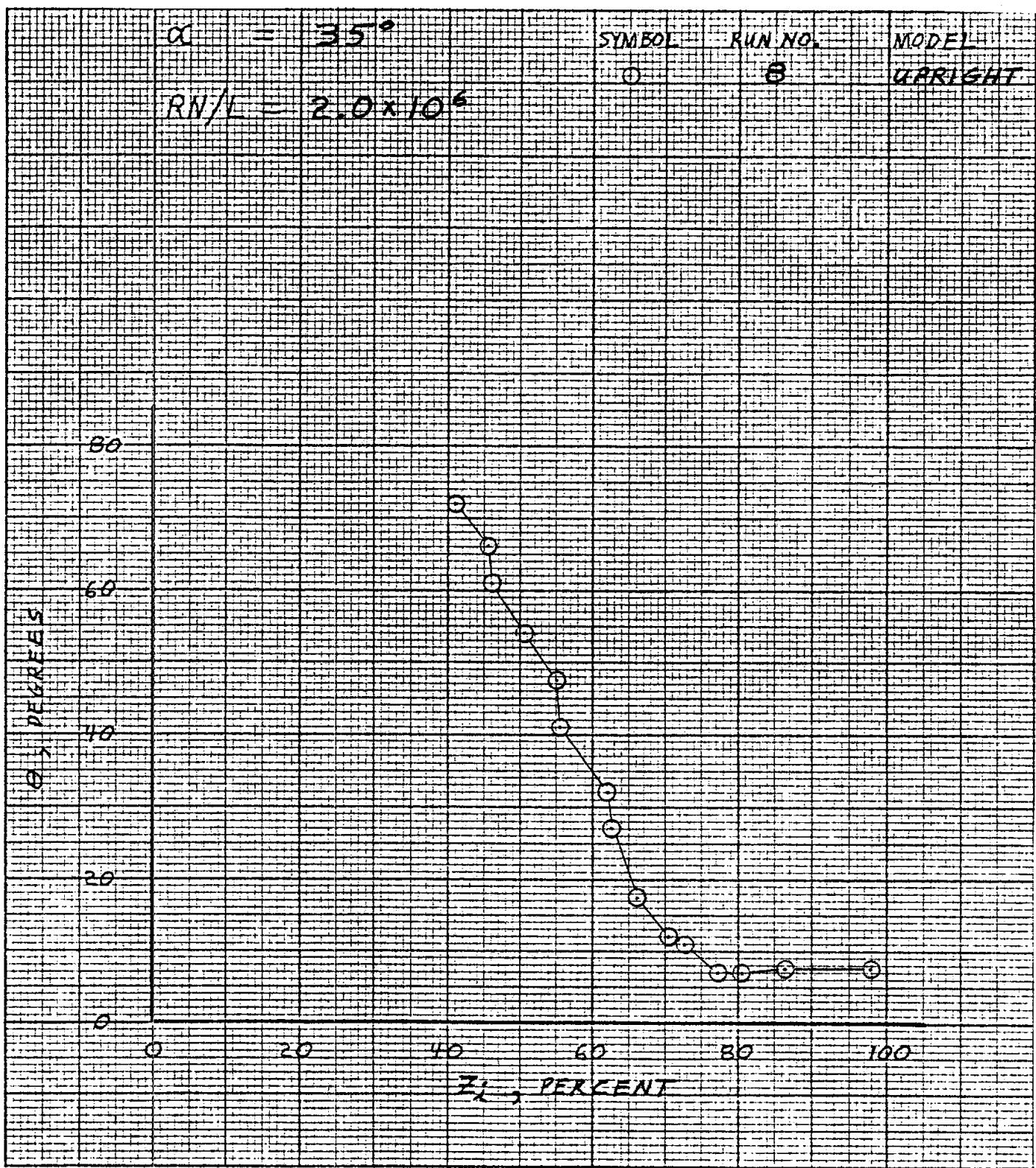


Figure 54. Flow Direction

$\alpha = 40^\circ$

$RN/L = 2.0 \times 10^6$

SYMBOL	RUN NO.	MODEL
○	7	UPRIGHT
□	36	INVERTED OIL REPLACED BY TURFS

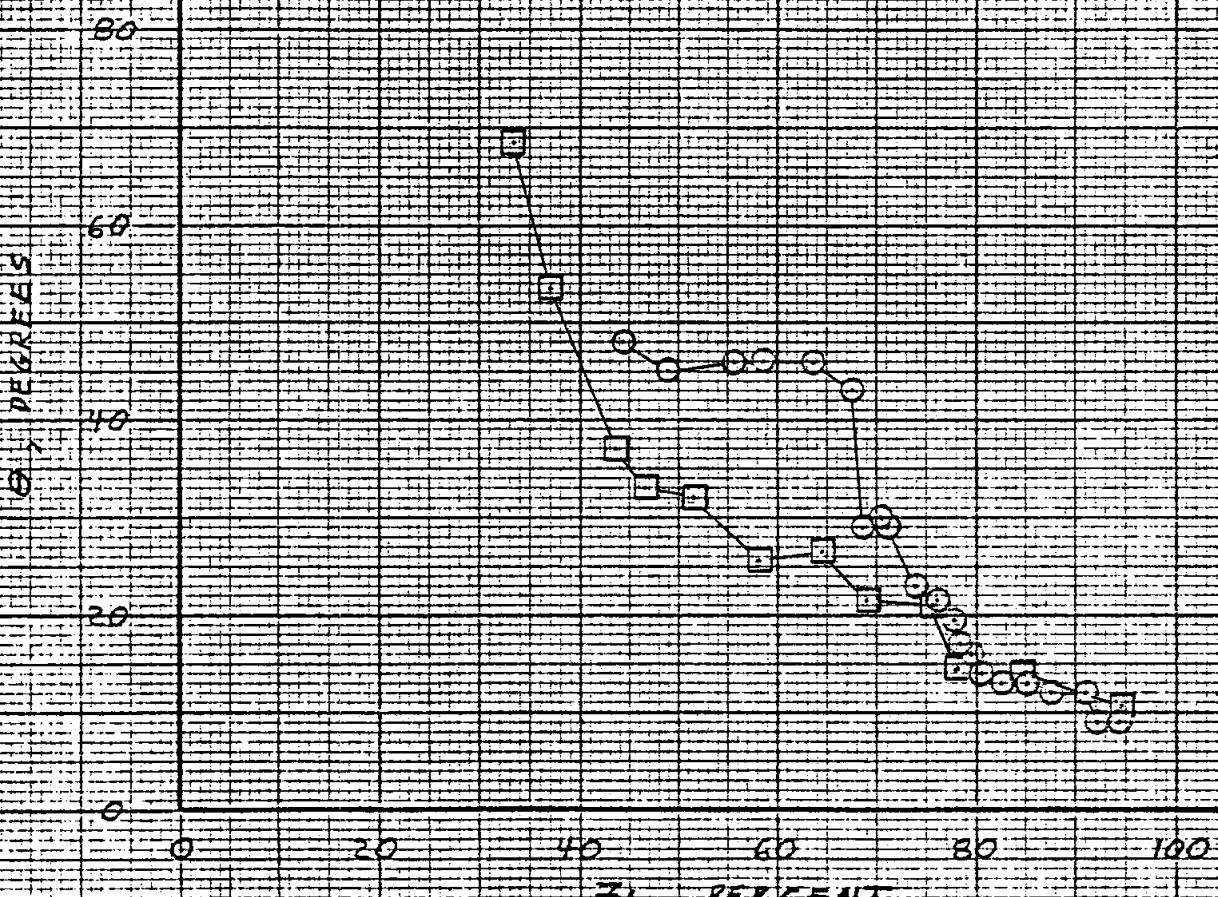


Figure 55. Flow Direction

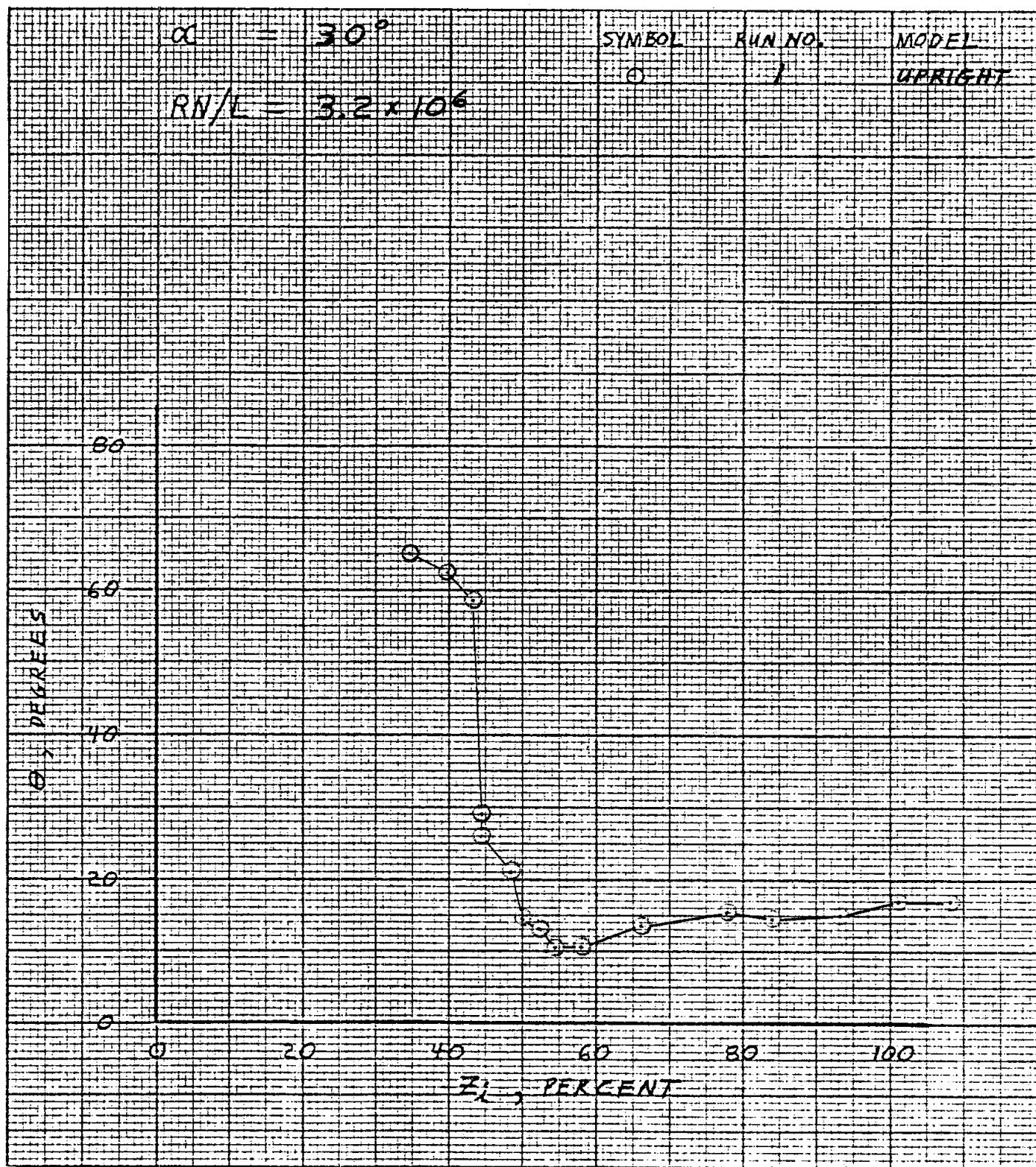


Figure 56. Flow Direction

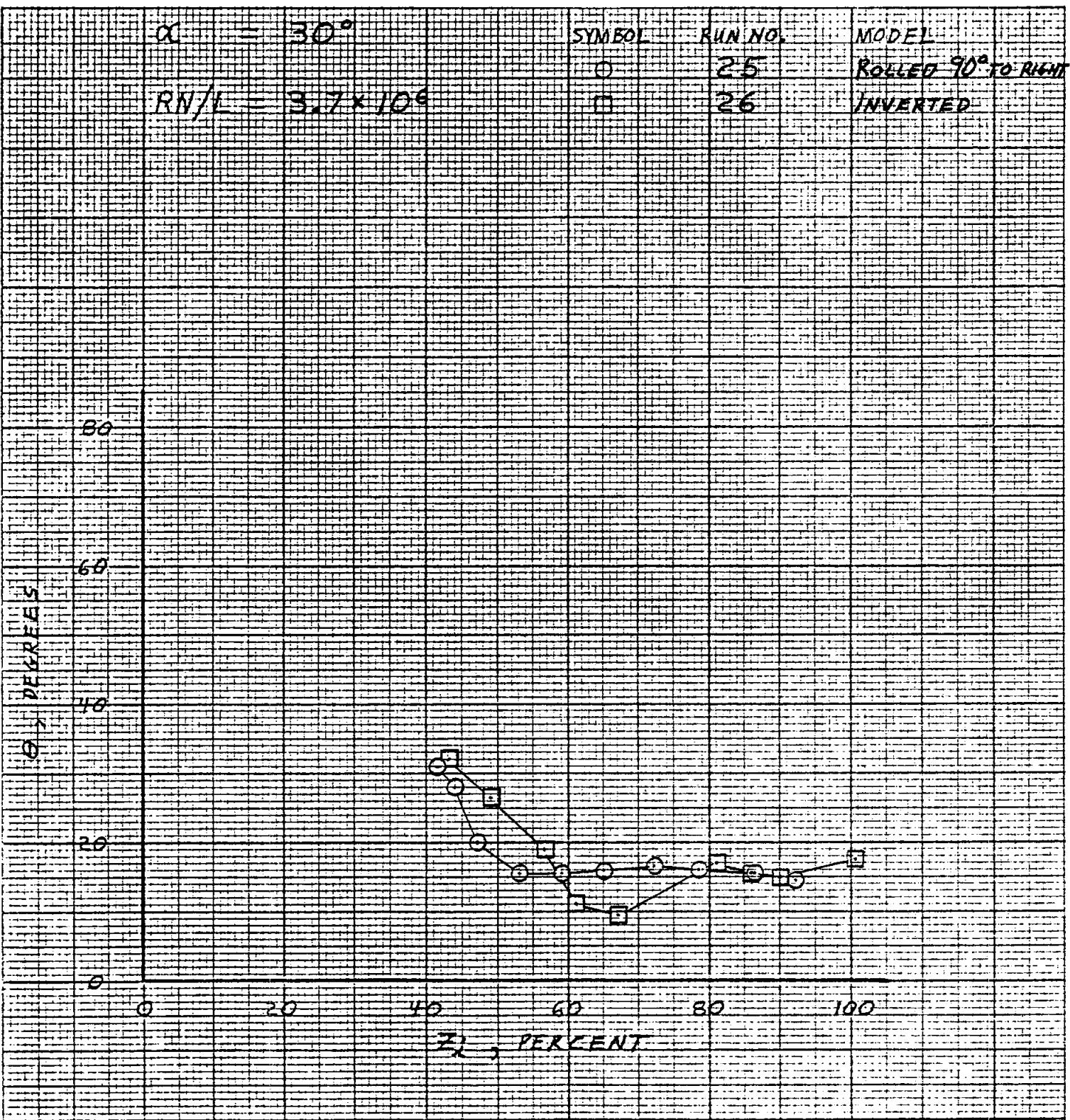


Figure 57. Flow Direction

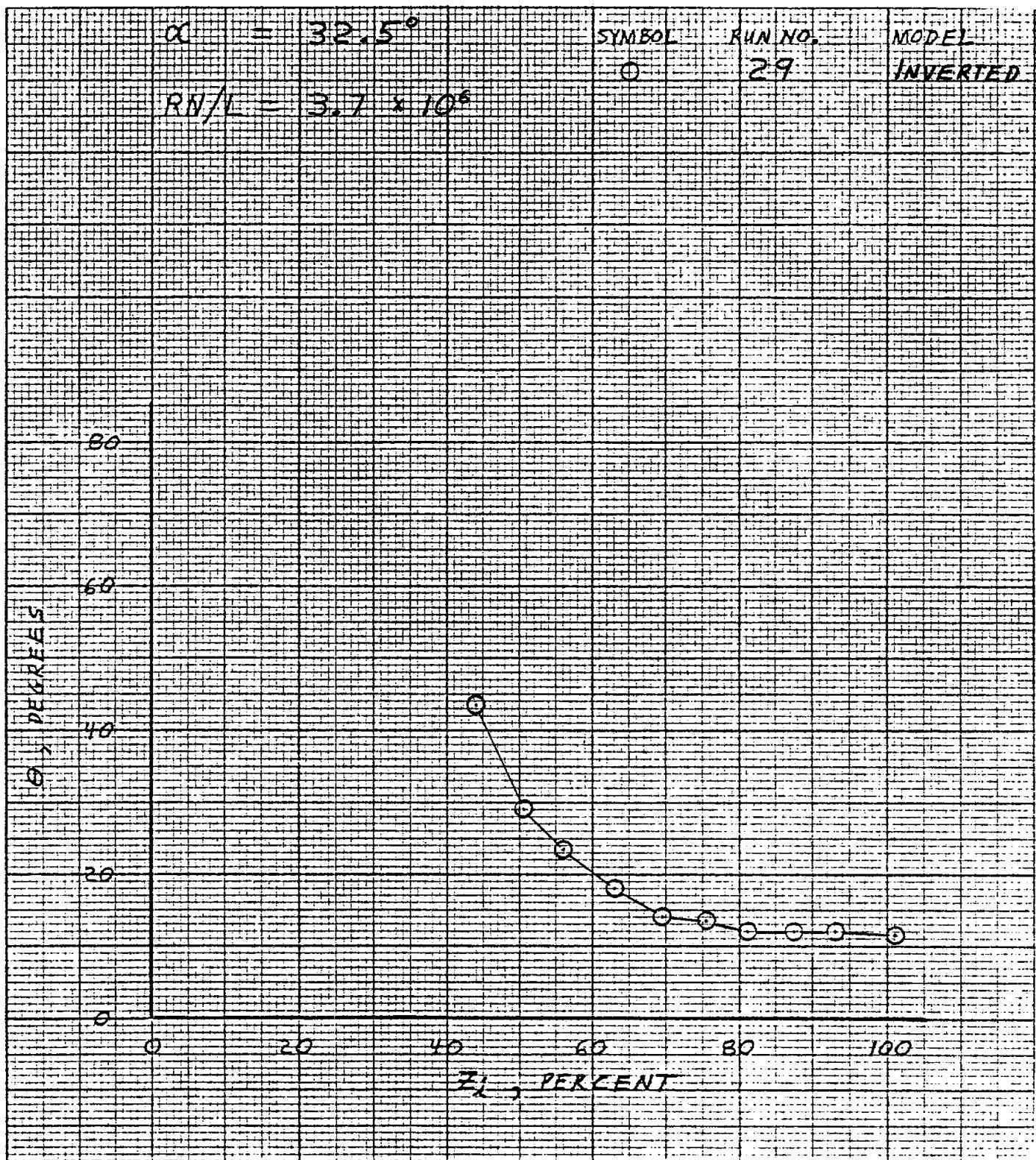


Figure 58. Flow Direction

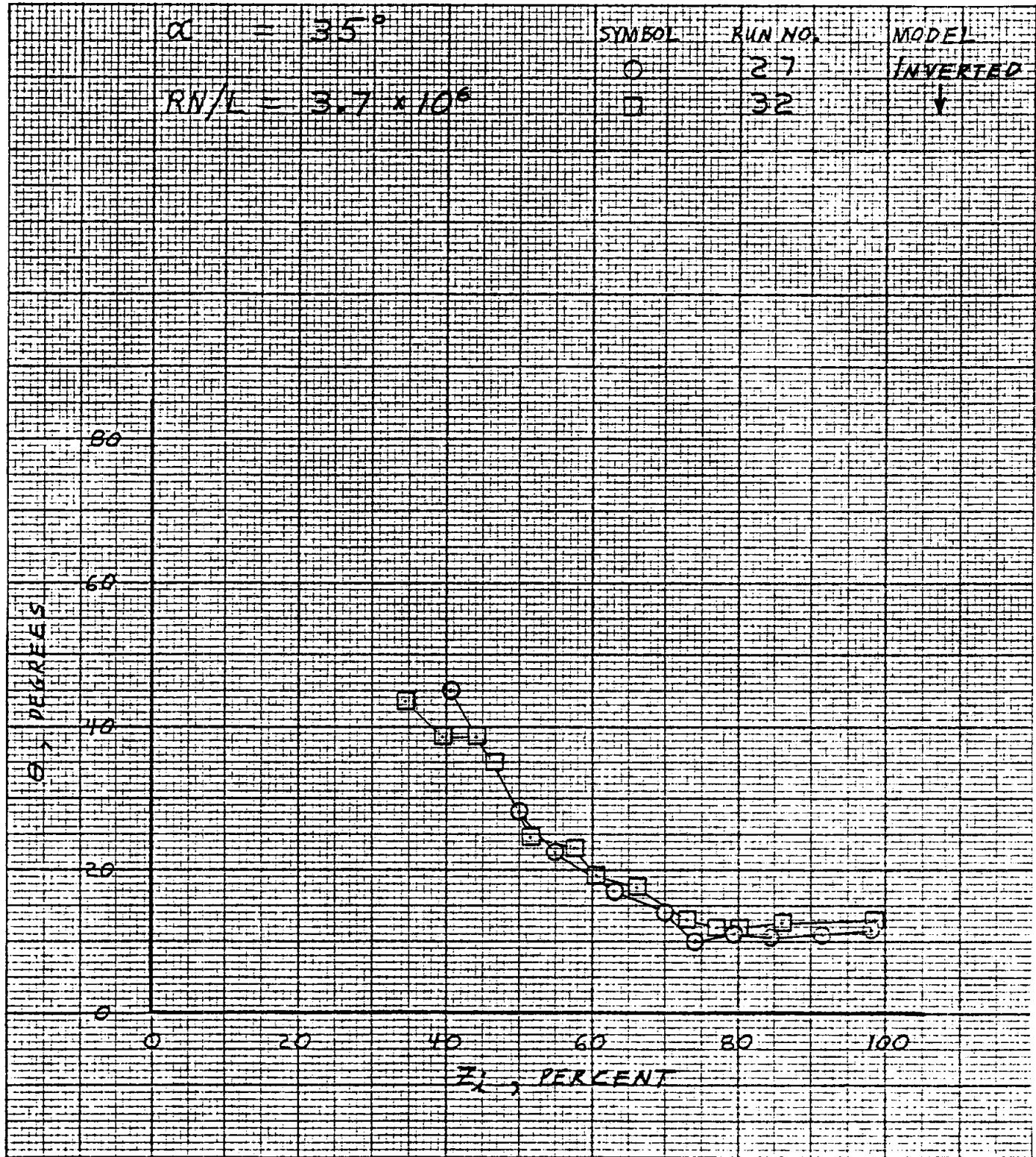
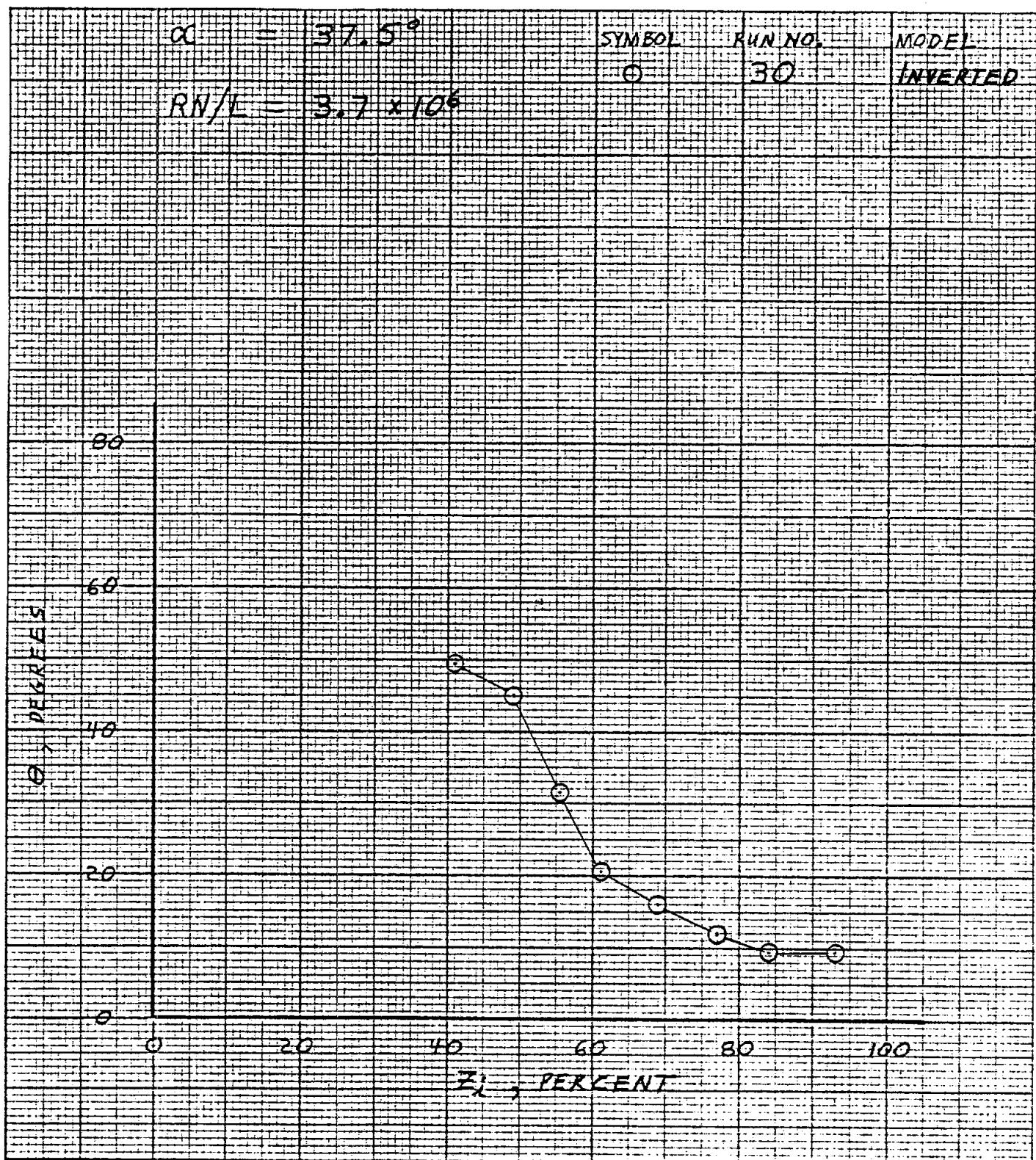


Figure 59. Flow Direction



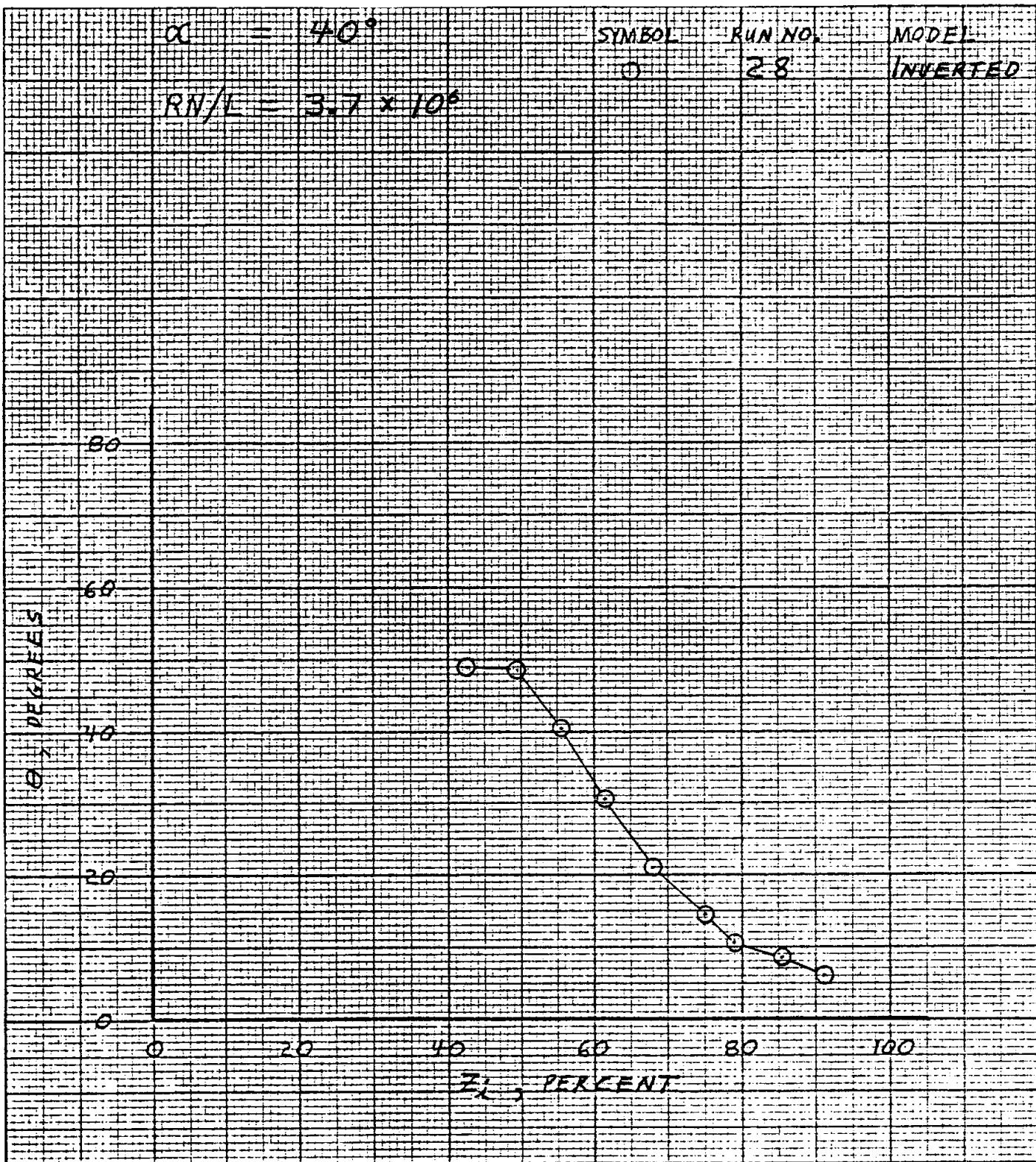


Figure 61. Flow Direction